NASA-CR-199465

O&S Analysis of Conceptual Space Vehicles

Prepared for

National Aeronautics and Space Administration

Langley Research Center

under

Grant No. NAG1-1-1327

Annual Report, Part I
December 31, 1995

Prepared by

Charles E. Ebeling

University of Dayton

Engineering Management and Systems Department

300 College Park

Dayton, Ohio 45469-0236

O&S Analysis of Conceptual Space Vehicles

Prepared for

National Aeronautics and Space Administration

Langley Research Center

under

Grant No. NAG1-1-1327

Annual Report, Part I
December 31, 1995

Prepared by

Charles E. Ebeling

University of Dayton

Engineering Management and Systems Department

300 College Park

Dayton, Ohio 45469-0236

Preface

This document is the fourth in a series of reports which began in June 1992 (see reference 14) under NASA (LRC) Grant No. NAG1-1-1327 to develop reliability and maintainability (R&M) models which can be used in support of the conceptual design of space transportation systems. The R&M model which has emerged from this research has experienced numerous modifications and enhancements. The latest set of changes to the model along with the use of the model in its present form is addressed in this report. Previous reports document earlier modifications to the model. Associated with this report is the second version of the User and Maintenance Manual developed for the Reliability and Maintainability (RAM) Model. The first version was completed in December 1994. Numerous changes have been made to the model during the current research year making the previous manual obsolete. As further experience with the model is obtained, additional changes and enhancements are likely. Planned future research includes updating the underlying data base used to generate the estimating equations.

The principle researcher for this effort is Dr. Charles Ebeling, Department of Engineering Management and Systems, School of Engineering, University of Dayton, Dayton, Ohio 45469. Comments concerning this document and the accompanying software are welcome.

TABLE OF CONTENTS

List of Tables

List of Illustrations

O&S Analysis of Conceptual Space Vehicles
Annual Report

1. Introduction

The University of Dayton is pleased to submit this report to the National Aeronautics and Space Administration (NASA), Langley Research Center, which discusses the application of recently developed computer models in determining operational capabilities and support requirements during the conceptual design of proposed space systems. This research makes use of the reliability and maintainability (R&M) model, the maintenance simulation model, and Operations and Support (O&S) cost model. In the process of applying these models, the R&M and O&S Costing models were updated. The nature of those updates are documented in this report. An updated verision of the R&M User's Manual has also been produced as part of this research effort. Other details concerning the R&M model and the O&S costing model may be found in previous reports accomplished under this grant (NASA Research Grant NAG-1-1327).

1.1 Background

Three primary models have been developed under this research grant each designed to address different aspects of the supportability and operability of proposed space vehicles. These models include the Reliability and Maintainability (R&M) model developed during the first two years of this grant, an O&S Costing model based in part on the logistics cost model developed by Rockwell and the shuttle R&M data study completed by Martin Marietta, and a computer simulation model of the operations and maintenance of a space transportation system. Much of these efforts are based upon comparability analysis with aircraft systems along with comparisons with corresponding space shuttle reliability and maintainability parameters, turn-around times, operational procedures, and operations and support costs. The R&M model has been developed to provide initial estimates of vehicle reliability and maintainability parameters. These estimates provide the input necessary to predict maintenance manpower, spares and turntime requirements. Although an initial estimate of manpower, spares, and turntimes can be obtained from the R&M model, the simulation model was designed to provide a more accurate analysis tool. The additional flexibility of the simulation model to consider explicitly the failure and repair distributions, the queuing effect of maintenance crews and repairable spares, and the operational dynamics of the number of vehicles, mission schedules, launch windows, and mission aborts, makes it a significantly more realistic tool for assessing operational capabilities and supportability. The output from the simulation model includes maintenance manpower requirements, repairable spare component requirements, vehicle turntimes and missions flown. Both the R&M model and the simulation model generate output which can be used by the O&S Costing Model as "cost drivers."

1.2 Research Objectives

The major objectives of this research are:

a. to perform a Reliability, Maintainability, and Suppostability (RM&S) conceptual design study,

b. to demonstrate and enhance the documentation of a viable study methodology which can be used on future vehicle design activities as part of NASA's R&M program, and,

c. to upgrade existing models, data, and procedures as necessary to support the study process.

1.3 References

Other reports completed as part of this research grant include:

1.3.1 "The Determination of Operational and Support Requirements and Costs During the Conceptual Design of Space Systems." Final Report. June 18, 1992.

Describes the data sources, methodology, analysis, and results of the initial parametrically generated reliability and maintainability model.

1.3.2 "Enhanced Methods for Determining Operational Capabilities and Support Costs for Proposed Space Systems." Final Report. June 1993.

Describes the integration of shuttle data, the development of the NASA WBS into 33 subsystems, numerous enhancements to the model, the (optional) addition of an external tank and liquid booster rocket, a redesign of the user interface, and compiled version of the model.

1.3.3 "Operations & Support Cost Modeling of Conceptual Space Vehicles." Annual Report. June 1993 - July 1994.

Presents an initial costing model to address operations and support costs. Integrates several different aircraft life cycle cost equations with shuttle derived values and direct user input based in part upon the following:

1.3.3.1 Forbis and Woodhead, Conceptual Design and Analysis of Hypervelocity Aerospace Vehicles: Vol 3. Cost, WL-TR-91-6003, Volume 3, BOEING Military Airplanes, Jul 1991.

1.3.3.2 Isaacs, R., N. Montanaro, F. Oliver, Modular Life Cycle Cost Model (MLCCM) for Advanced Aircraft Systems-Phase III, Vol VI, Grumman Aerospace, Jun 1985.

1.3.3.3 Kamrath, Knight, Quinn, Stamps, PREVAIL: Algorithms for Conceptual Design of Space Transportation Systems, Feb 1987.

1.3.3.4 Logistics Cost Analysis Model, Advanced Manned Launch System (AMLS) Task Assignment 5, Rockwell International, Space Systems Division, September 10, 1993.

1.3.3.5 Marks, Massey, Bradley, and Lu, A New Approach to Modeling the Cost of Ownership for Aircraft Systems, RAND, Aug 1981.

1.3.4 "Integrating O&S Models During Conceptual Design - Part I," December 31, 1994.

1.3.4 "Integrating O&S Models During Conceptual Design - Part II, Reliability and Maintainability Model (RAM), User and Maintenance Manual." December 31, 1994.

Provides detailed user documentation of the RAM model as well as source listings, a complete glossary, flow charts, menu hierarchy, and step by step procedures for using the model.

1.3.5 "Integrating O&S Models During Conceptual Design - Part III, Simulation of Maintenance and Logistics Support of Proposed Spaces Systems Using SLAM II." December 31, 1994.

Documents the SLAM maintenance model including a complete example.

1.3.6 "RAM User and Maintenance Manual," December 31, 1995.

2. Model Changes and Enhancements

One of the research objectives is to upgrade the models as necessary to support the study process. Several enhancements and changes have been made to each of the three models relative to their earlier versions. The majority of the R&M model changes have resulted from LRC's validation of the model based upon shuttle design and performance characteristics.

2.1 R&M Model Enhancements

2.1.1 Average Missions per Year and Computed Fleet Size

In order to account for the difference in working days per month (approximately 21) and mission days per month (an average of 30.44) in the calculation of the average missions per year per vehicle and average fleet size, a weighted average of these two values were computed based upon the mission length in days. The formula used is:
Days/month = [(turnaround days - Msn days) 21 + Msn days x 30.44] / turnaround days

where turnaround days is the elapsed days from launch to recovery and the subsequent completion of all scheduled and unscheduled maintenance tasks. This change was necessary to account for differences for example between long shuttle missions times (e.g. 10 days) and short mission durations (e.g. 72 hours) in support of the space station.

2.1.2 Tank subsystem changes.

In the aircraft mode, separate but identical regression equations are evaluated for the LOX tanks and the LH2 tanks to obtain their respective MTBMAs. This equation was frequently obtaining its lower bound. The following new regression equation was derived which is more responsive to tank weight:

$$\text{MTBMA} = 19.4846 - .000194 \times \text{tank weight} - .000118 \times \text{main engine weight} \quad (R = .85)$$

where the MTBMA $\geq$ .05.

Two changes were made to the manhours per maintenance action (MH/MA) calculation. First each tank subsystem has its MH/MA computed separated based in part upon individual subsystem weights. Previous a single value was computed using their combined weights with the same MH/MA assigned to both subsystems. Second, the following new parametric equation was derived:

$$\text{MH/MA} = -4.6274 - .65\,(\#\text{ tanks}) - .000386\,(\text{subsystem weight}) + 2.98686\log(\text{subsystem weight}) \quad (R = .94)$$

2.1.3 Inherent Failures

The ability to freeze the inherent and external MTBM's rather than have these values recomputed upon execution has been added. Since these MTBMs are normally computed using the adjusted MTBM and the specified operating hours, this allows for changes in mission hours and ground processing hours without changing the MTBMs.

2.1.4 Additional Manpower Calculations

Maintenance manpower is computed based upon the maximum of the manpower earned based upon manhours and the manpower earned based upon the assigned number of crews. Assigned crew levels are user specified and would normally be based upon achieving a desired turntime or fleetsize. To convert assigned crews to manpower, the following formula is used:

Asgn manpwr = PMF x asgn positions (rounded up)

where PMF = position manning factor

= [21 days/mo x 8 hrs/day] / [(1-indirect %) x avail hrs/mo], and

Asgn positions = assigned crews x average crew size (rounded up).

The basic premise behind the computation of the assigned manpower is that the specified number of crews represents positions which must be manned continuously over the shift in order to support desired vehicle maintenance turntimes and fleetsizes. Final manpower, referred to as Max Manpower is then found from: max manpower = MAX { manhour earned manpower, asgn manpower}.

2.1.5 Phase Inspection Manpower

The option to include a periodic (phase) maintenance manpower requirement has been included. This manpower is in addition to the scheduled manpower which is based upon a fixed percent of the unscheduled manhours of work or user specified. Phase inspection manpower is computed from the following formula:

Inspection manpower =

[crew size x # days per phase x msn/mo] / {[# msns btwn phase] [(1-indirect %) x avail hrs/mo]} (rounded up)

Therefore total manpower = max manpower + Phase manpower + PAD manpower

PAD manpower is user specified as a system input parameter.

2.1.6 Output to a File

The option to print each report has been deleted in order to free memory for additional features. As a result, the Summary Output Report and the Agregated Systems Report are now written to the ASCII file which may then be read, edited, and printed by most word processors. Users with parallel port printers may still do a "print screen" command as an alternative to printing the ASCII file.

2.1.7 Additional Turntime Calculations

An average turntime is now computed in the following manner:

Max turn time = Σ mission task times + avg phase inspection time

Min turn time = MAX { mission task times}

Avg turn time = (1 - frac) x Min turn time + frac x Max turn time

where f = fraction or weight placed upon the maximum turn time, 0 < frac < 1. Frac has been included on the input parameter menu (X_{20}). To obtain turntimes, the above times are then added to mission time + PAD time + Integration time. A vehicle maintenance turntime which does not include the mission time has also been added to the turntime report and the summary report. Phase or periodic inspection times are included as the minimum turntime if it exceeds the maximum subsystem task time.

2.1.8 Redefined Spares Calculation

The mean number of spares required is now based upon a component repair (or resupply) cycle time rather than being a per mission average. The computed number of spares is therefore sensitive to the annual mission rate and represents the number of spares needed to fill the repair pipeline at the specified fill rate. The formula is given by:

mean nbr spares = λ T , where

λ = removal rate/ MA x operating hours / MTBF x missions/yr

and T = repair or resupply time in years. The mean number of spares, λT, is the mean of a Poisson distribution which is then used to determine the total number of spares required to achieve the fill rate goal. For large mean values (greater than 20), the normal approximation is used where

Total number spares = $\lambda T + z\sqrt{\lambda T}$ and z is the normal deviate corresponding to the fill rate goal (e.g. for a fill rate goal of .95, z = 1.65).

2.1.9 Shuttle MTTR Conversion

In order to maintain consistency in the way "aircraft" selected subsystems and "shuttle" selected subsystems are processed, the maintainability parameter for the shuttle (or user input) was changed from the MTTR to manhours per maintenance actions (MH/MA). The MTTR is subsequently computed by dividing the MH/MA by the subsystem crew size. Since the "aircraft" mode begins by computing the MH/MA parametrically and then computes the MTTR, changes to crew sizes will now affect the MTTR for both cases in the same way.

2.1.10 Weight Parametric Analysis

Baseline subsystem weights can now be maintained while the weights being used in the calculations (referred to as the current weight) can vary by a constant factor. At any time, the baseline weight may be restored as the current weight. This change permits the analyst to systematically vary subsystem weights while observing the effect on the R&M output parameters.

2.1.11 Scheduled Maintenance

Scheduled maintenance is now computed by subsystem and included in the total subsystem maintenance time used in the turntime calculations. The analyst can specify individual subsystem scheduled maintenance hours or specify the percent of unscheduled maintenance hours to be used to determine the total scheduled maintenance hours. This total is then allocated to the subsystems based upon their relative weight distribution.

2.1.12 Space Adjustment

When specifying a subsystem MTBM, the option now exists to select "SHUTTLE" or "ADJ-MTBM". If "SHUTTLE" is selected, then the space adjustment will normally not be applied (unless the space adjustment system parameter indicates otherwise). If "ADJ-MTBM" is selected, then the space adsjustment is applied to that particular subsystem. As a result, the user may now apply the space adjustment selectively rather than globally. The space adjustment is usually not applied to shuttle data since these data already reflect operating in a space environment. If an aircraft or other derived MTBM is used which has not accounted for the space environment, then the adjustment would normally be made.

2.1.13 Parametric Analysis

In order to support parametric and sensitivity analysis, a set of predetermined output values and a user specified input value are now written to a file each time the model is recomputed. While in the parametric analysis mode, the user may systematically change one or more input parameters each time recomputing and saving the output values. This (ASCII) file may then be imported into a spreadsheet (e.g. EXCEL) for subsequent graphing and analysis. There are also two "wild card" parameter values which the user can specify each time the model is recomputed. Current file contents are displayed each time the model is recomputed while in the parametric analysis mode.

2.1.14 Computational Factor Averages

For the computational factors (technology growth rate, critical failure rate, subsystem removal rate, MTBM/MHMA calibration factors, crew sizes, assigned crews, fraction off vehicle, and fraction inherent failures) an average value is computed and displayed at the bottom of the input screen. This provides a single vehicle level measure useful in conducting trade studies and sensitivity analysis.

2.1.15 MPS Subsystem

A MPS Propulsion subsystem has been added as the 34th subsystem in order to distinguish between the main engines subsystem and the the remainder of the propulsion system. This subsystem contains components which for aircraft are found in both the engine subsystem and the fuels subsystem. Therefore, in order to estimate the MTBM, MHMA, Removal Rate, Abort Rate, and Crew Size, simple averages of these parameters as determined by the engine and fuel equations are used within the model. The MPS subsystem is incorporated into the aggregated system structure as shown in the following table.

Table 2.1
Aggregate Subsystems

Aggregate System	Subsystem	WBS
Structures	Wing Group	1.00
	Tail Group	2.00
	Body Group	3.00
Power Systems	APU	9.10
	Battery	9.20
	Fuel Cell	9.30
	Electrical	10.00
Tanks	LOX	3.10
	LH2	3.20
Propulsion	Main Engines	6.00
	MPS	**6.10**
	RCS	7.00
	OMS	8.00
Avionics	GN&C	13.10
	Health Monitoring	13.20
	Communication & Tracking	13.30
	Displays & Controls	13.40
	Instruments	13.50
	Data Processing	13.60
Thermal Protection Tiles		4.10
	TCS	4.20
	PVD	4.30
Mechanical Systems	Landing Gear	5.00
	Hydraulics	11.00
	Aero Surfaces/actuators	12.00
Life Support	Environmental Control	14.10
	Life Support	14.20
	Personnel Provisions	15.00
	Rec & Aux - Parachutes	16.10
	Rec & Aux - Escape Sys	16.20
Auxiliary Systems	Rec & Aux - Separation	16.30
	Rec & Aux - Cross-feed	16.40
	Rec & Aux - Docking Sys	16.50
	Rec & Aux - Manipulator	16.60

2.2 O&S Cost Model Changes

The primary change to the Operations and Support Costing (OSC) model was the incorporation of new formulas used by the Logistics Cost Model (LCM) for computing depot and organizational recurring and nonrecurring training costs and documentation costs, and depot support equipment (DSE) costs. The new formulas required adding several input parameters while several others were deleted since they were no longer used. A module to write the input parameters and cost factors and the WBS cost summary to a (ASCII) file was added. This facilitates writing reports since the file may be easily imported into a word-processing document. The RAM input module and a display module to the model also had to be modified to accomodate the change in the RAM model from 33 to 34 subsystems.

3. Conceptual Design Study

A major objective of this research is to demonstrate the use of the R&M model along with a viable study methodology. In this regard, a case study of the conceptual design process is documented. The case study is based upon a winged, single-stage, vertical-takeoff vehicle (SSV) designed to deliver to the Space Station Freedom (SSF) a 25,000 pound payload including passengers without a crew. Launch and recovery (horizontal landing) would occur at the Kennedy Space Center (KSC).

To begin the study process, a basecase R&M analysis is conducted using currently accepted design and performance parameters based upon a LRC baseline Access-to-Space Study. Appendix A contains a general vehicle description obtained from NASA (LRC). Significant input parameters to the model include a technology year of 2007 and a five day mission duration with 30 missions a year planned. The model is run in mode 3 (weight and variable driven) with subsystem weights and input parameters based upon a NASA April 1994 weight statement and design and sizing parameters statement (appendix B).

3.1 Initial Model Runs

Input parameters are contained in Appendix C. Most system parameters, technology growth rates, critical failure rates, removal rates, fraction inherent failures, and fraction off-vehicle work, were based upon the model default values. Scheduled maintenance was based upon a parametrically computed 52.92 percent of the unscheduled maintenance determined by subsystem. An adjustment was then made to account separately for the scheduled maintenance of tiles. No periodic maintenance was included. The IEP (tiles, TCS, PVD) subsystems, fuel cells, RP tanks, and the Main Propulsion System (MPS) were based upon user specified (shuttle default values) defined MTBMs, crew sizes, and MHMAs. All other subsystem parameters were computed from the aircraft equations with the environment adjustment (launch and space) applied. For nominal turntime calculations a proration of one tenth of the maximum turntime and nine-tenths of the minimum turntimes was used. Reliability growth was not included in the basecase. The only subsystem redundancy was a six out of seven main engine requirement.

An initial model run indicated (Manpower Report) that based upon the man-hours of work generated, two maintenance crews for the body group subsystem, 7 crews for the tile subsystem, and two crews for the environmental control subsystem were necessary. For the remaining subsystems, a single crew was sufficient to meet the maintenance man-hour requirements. Therefore these numbers of crews were assigned within the model, and the model rerun. The resulting output (Appendix D) establishes the basecase.

3.2 Manpower Analysis

In order to establish a final manpower requirement, a vehicle turntime goal of 6 ground processing days is established. The basecase manpower (assigned crews) of ???? provided an 8 day ground processing time. Therefore additional crews would have to be assigned in order to further reduce this time. The Turntime Report indicated that tiles, ECS, TCS, and the body group subsystems were contributing the most to the vehicle processing time. Therefore two additional crews were assigned to tiles, and one additional crew to each of the other three subsystems. When converted to earned manpower, this resulted in a requirement of 173 an increase of 25. The resulting ground processing time was 6.5 days, still somewhat higher than the 6 day average goal. Therefore an additional tile crew and ECS crew were added since these two subsystems had the first and second largest subsystem turntimes respectively. The final manpower requirement was 180. This analysis is summarized in the following table.

	Basecase	Run #2	Run #3
Tile Crews	7	9	10
ECS Crews	2	3	4
TCS Crews	1	2	2
Body Grp Crews	2	3	3
Turntime(days)	8	6.5	6.0
Total Manpower*	148	173	180

Table 3.1 Manpower Analysis *excludes PAD manpower

Once the turntime goal was reached, attempts were made to reduce individually by one crew each of the above subsystems. In each case the turntime then exceeded the goal. Therefore, it was concluded, the above manpower was the minimum number needed to support the mission requirements. In all cases, the model indicated that 2 vehicles would be necessary to maintain the 30 missions per year flight rate.

3.3 Parametric Analysis

Because many of the system and subsystem input parameters were based upon (aircraft) default values, a sensitivity analysis is performed on several of the more important parameters in order to determine how critical these parameters are to overall vehicle R&M performance. In collecting the following data, the model parametric analysis option was used.

3.3.1 Weight Factor

Individual subsystem weights or overall vehicle dry weight are primary drivers in most of the regression equations. The basecase dry weight is 174,160 pounds. Weight factors of .9, .8, 1.1, and 1.2 were applied to each subsystem to account for changes in overall vehicle and subsystem weights from the nominal case. The following sensitivity curve

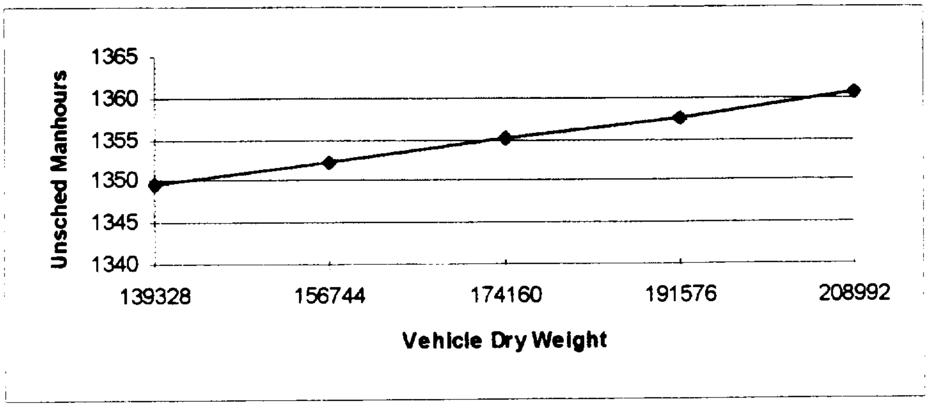


Figure 3.1 Weight Analysis

shows that the total unscheduled man-hours of work per mission will not change significantly even with a relatively large change in the vehicle dry weight. The number of maintenance actions per mission did not change significantly (slight increases only) while the man-hour per MA may actually decrease in some cases as the subsystem increases in size (i.e. weight). For most subsystems, weight is not the dominating R&M "driver."

3.3.2 MTBM Adjustment factor

The mean time between maintenance actions whether before or after the technology adjustment is performed is a key output parameter since it directly affects the mission reliability (critical failures) and the overall number of maintenance actions generated per mission. The calibration factor was systematically changed from .8 to 3.0 in order to generate a range of values for all subsystem MTBMs. Mission reliability is impacted as expected. Obviously, as the MTBM improves reliability will continue to increase but at a decreasing rate as it approaches 100 percent.

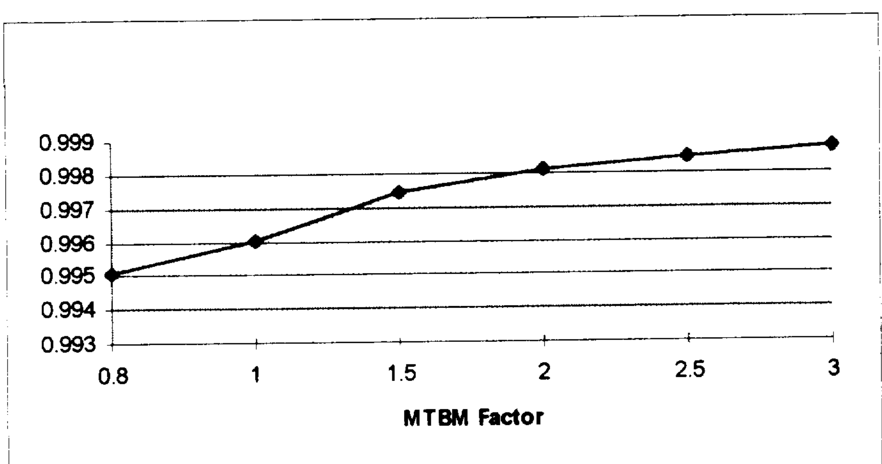


Figure 3.2 Reliability vs MTBM Factor

As reliability improves as a result of an improvement in the MTBM, a significant decrease is observed in both the number of spares needed to fill the pipeline and the amount of manpower needed. The manpower requirement begins to level off at a factor of 2.5. There is a minimum requirement to staff at least one crew for each subsystem and therefore any further increase in reliability will have no effect on manpower. Spares will continue to decrease as the MTBM increases approaching a lower bound of zero when the expected number of unserviceable spares in resupply is sufficiently small (i.e. a fractional value).

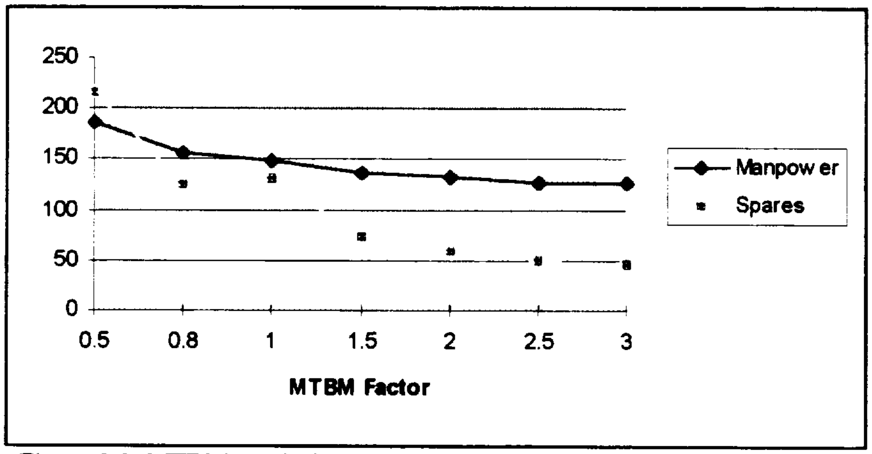


Figure 3.3 MTBM Analysis

3.3.3 MHMA Factor

The MHMA factor provides an adjustment to the computed (or specified) man-hours per maintenance action. This multiplicative factor can account for qualitative changes in technology (such as new structural material or alternative power sources) from the technology reflected in the data base. It may also be used to account for differences between the aircraft derived data and its use within the space vehicle environment. A third alternative use is for sensitivity analysis as illustrated in Figure 3.4. Since the MTTR is computed by dividing the MHMA by the average crew size, increasing the MHMA is equivalent to increasing the MTTR. Unlike the MTBM factor, changes to the MHMA have no impact on mission reliability.

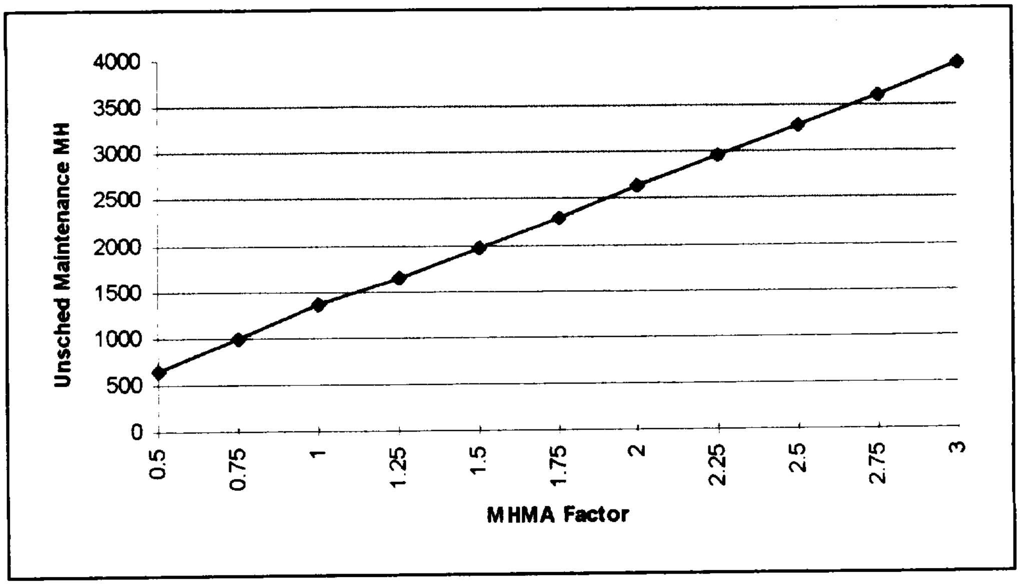


Figure 3.4 MHMA Factor

However, the effect of systematic changes in the MHMA using factors ranging from .5 to 3 on unscheduled maintenance hours is a nearly linear increase as expected. This differs therefore from the effect of changes in the MTBM (paragraph 3.3.2) in which nonlinear changes in manpower and spares requirements were observed.

3.3.4 Launch Factor

The launch factor defaults to 20. This results in a constant failure rate of twenty times the (aircraft) equation computed or user specified failure rate during the period of time during launch when the vehicle is under booster rockets. This is assumed to be the period of greatest vibration and other stresses placed on many of the subsystems.

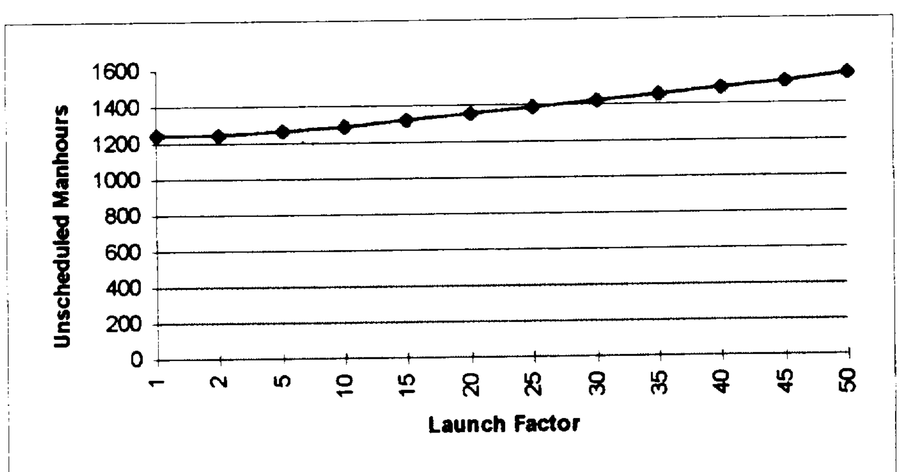


Figure 3.5 Launch Factor

From Figure 3.5, it can be seen that the unscheduled man-hours of work will change somewhat significantly with a change in the launch factor. As the man-hours change, manpower requirements and turntime will also be impacted. Mission reliability changed from .99895 to

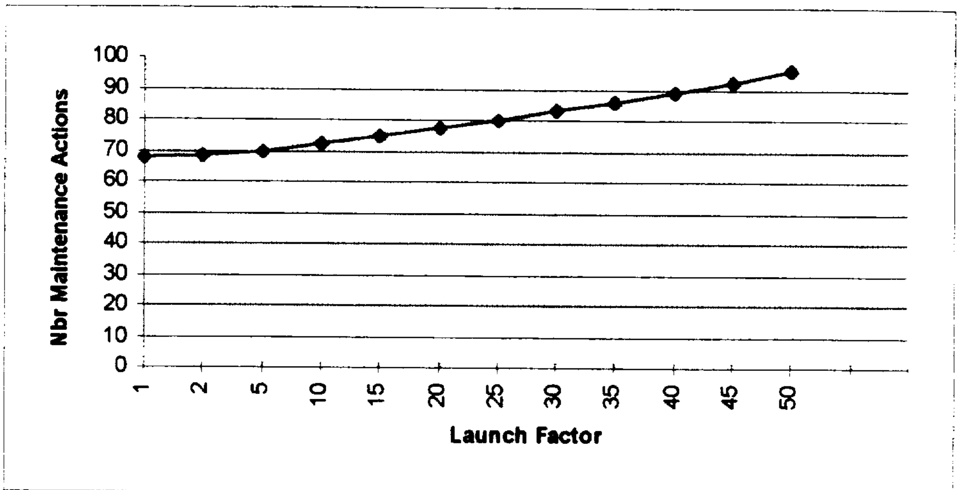


Figure 3.6 Launch Factor vs Maintenance Action

.9792. A significant drop considering the small time duration associated with the booster phase of the mission. Figure 3.6 shows the large increase in maintenance actions generated as a result of this increase.

3.3.5 Weibull Shape Parameter

The default value for the Weibull shape parameter is .28. This is based upon an average value determined from a large set of satellite system failure data. Studies have shown that failure rates of subsystems while in orbit will decrease over time. When the shape parameter is equal to one (1), then the Weibull distribution is the same as the exponential distribution and the failure rate is constant.

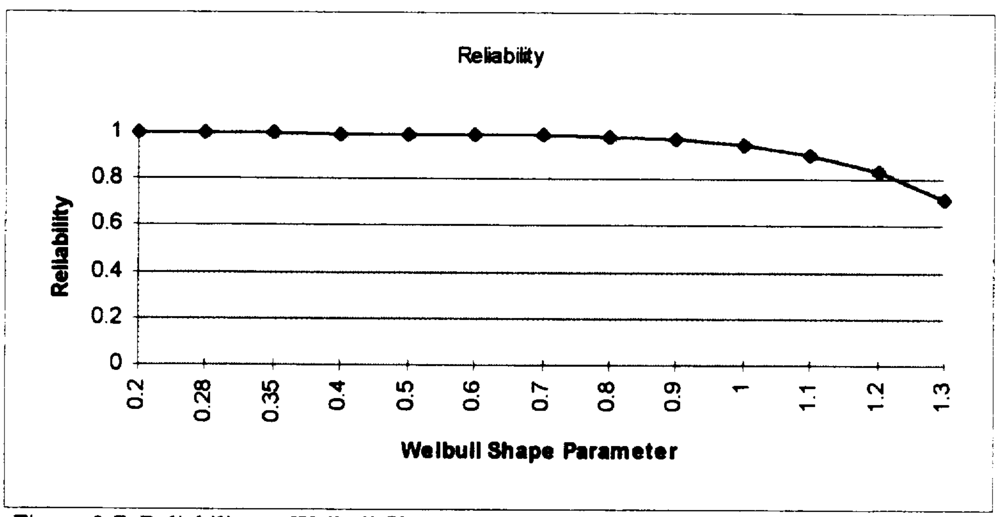


Figure 3.7 Reliability vs Weibull Shape Parameter

Figure 3.7 indicates that the vehicle reliability is relatively insensitive for values of the shape parameter below .7. If a constant failure rate is assumed (i.e. the shape parameter is 1), then a noticeable degradation in reliability will be observed. Obviously, if increasing failure rates are observed, the reliability will be significantly decreased.

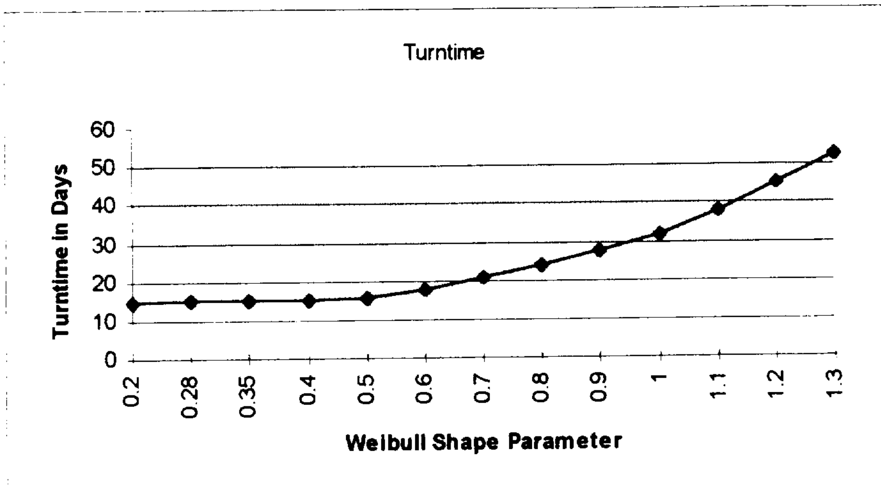


Figure 3.8 Turntime vs Weibull Shape Parameter

A similar effect of the shape parameter on vehicle turntime and unscheduled maintenance man-hours are also seen with degradation occurring above a .5 shape parameter.

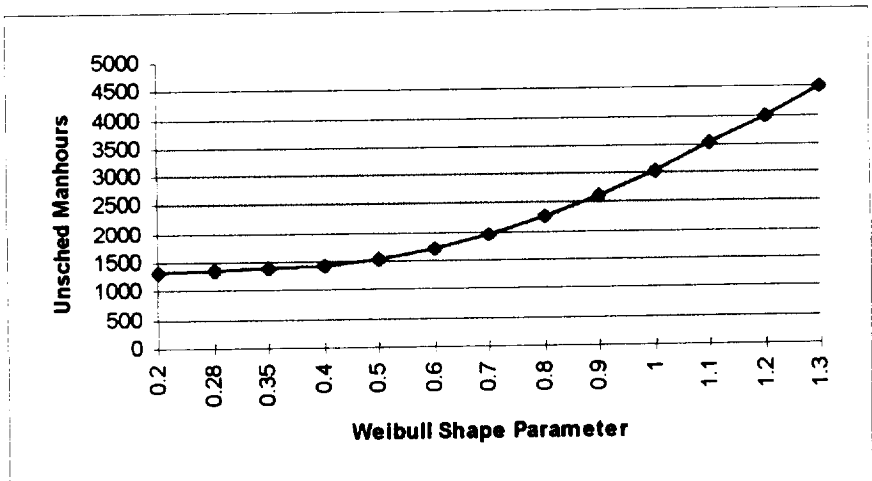


Figure 3.9 Weibull Shape Parameter vs Unscheduled Man-hours

3.3.6 Technology Year

For each subsystem, a technology growth rate is specified (it may be zero). This annual rate is applied to the initial MTBM in order to account for improved reliability over the current data base during the intervening years leading to the development of the vehicle. The technology year represents the year in which the technology is incorporated into the vehicle. The following graph shows the decrease in man-hour driven manpower and spares as a function of the technology year. The primary assumption is that the subsystem growth rate will be experienced up to the technology year.

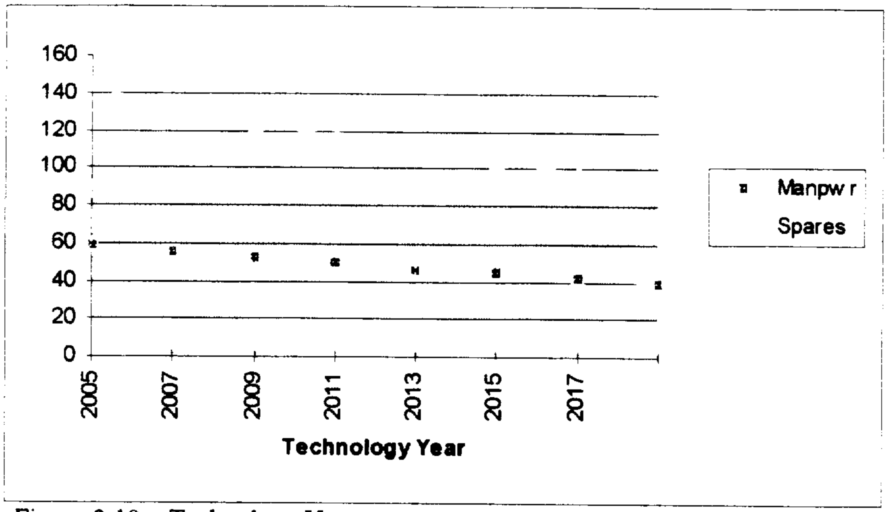


Figure 3.10 Technology Year

The effect of the technology on the number of maintenance actions generated per mission is shown in Figure 3.11. From the curve, it can be seen that the reliability improves at a slightly nonlinear rate over a 14 year period.

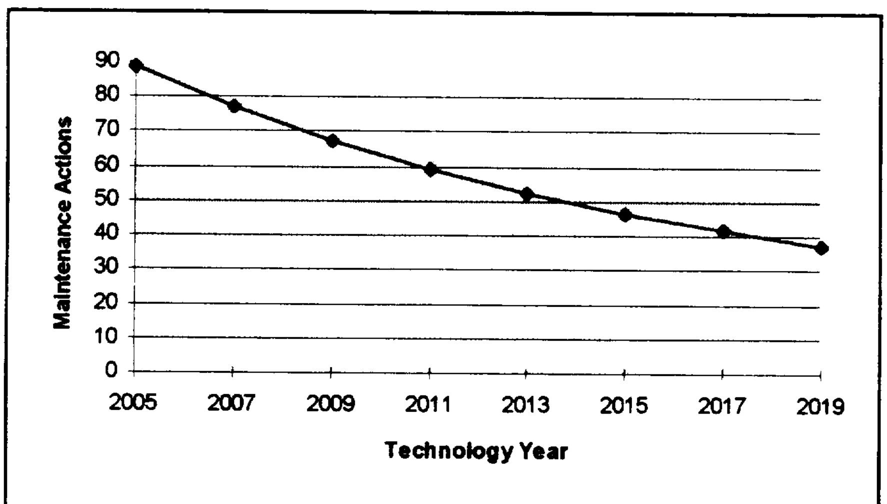


Figure 3.11 MA's vs Technology Year

3.3.7 Man-hour Availability

The monthly man-hour availability (default is 144 hours) is the average number of hours a month an individual is available for within the work place for performing both direct (e.g. maintenance) work and indirect (e.g. attend meetings, administrative chores, cleanup, training, etc.). There is a direct inverse relationship between the available hours and the number of maintenance personnel required. For the basecase, this relationship is quantified in Figure 3.12.

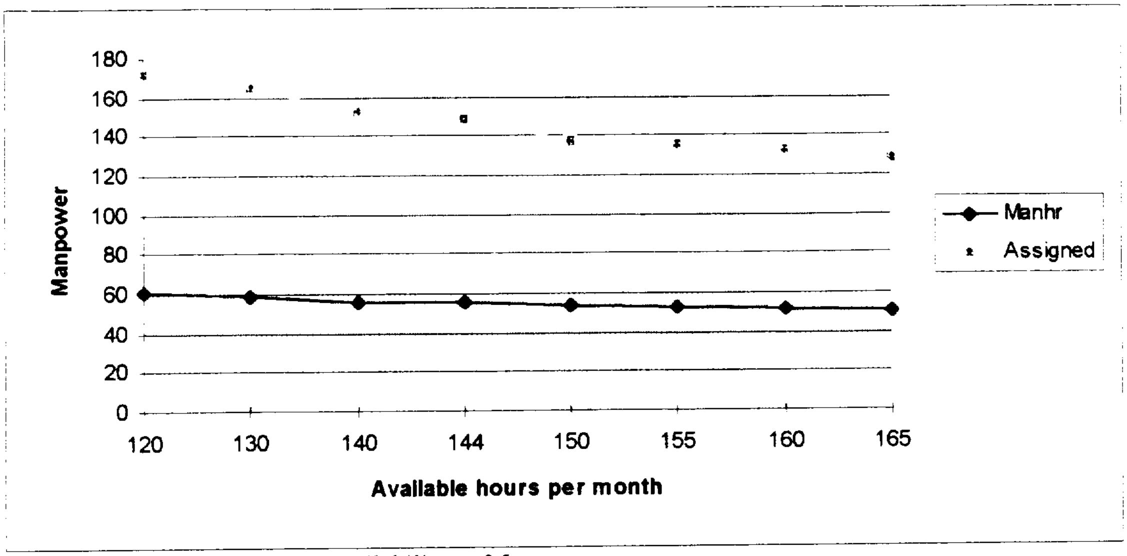


Figure 3.12 Man-hour Availability vs Manpower

Both the man-hour driven manpower and the required assigned manpower based upon assigned crew sizes are shown. Because of rounding, there is an observed step function effect. A similar effect would be observed if the direct/indirect percentages were changed since the direct percentage is a multiplier of the available hours.

3.3.8 Reliability Growth

Reliability growth is based upon the following growth curve:

$$MTBM = TECH\ ADJ\ MTBM \times MSN\ NBR^{b}\ .$$

The application of this curve assumes that reliability growth is a function of the number of missions flown, and that it continues at least through the mission number specified. By running the model at different mission numbers, a snapshot of the performance of the system over time may be determined. Figure 3.13 shows the effect of mission number (missions 1 to 50) and growth curve slope (b) on the overall vehicle MTBM.

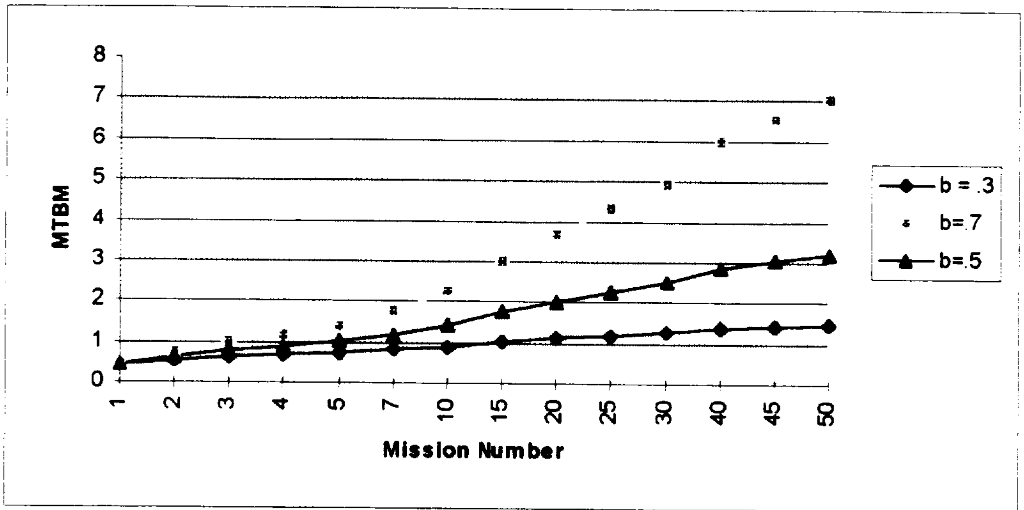


Figure 3.13 Reliability Growth Curves

The effect of reliability growth on mission reliability and the number of maintenance actions is shown in Table 3.2. A snapshot of vehicle performance is taken at missions 1, 25, and 50 at each of the three growth rates.

b	Mission 1	Mission 25	Mission 50
.3	.9960/77.3	.9985/27.2	.9988/21.9
.5	9960/77.3	.9990/14.0	.9994/9.9
.7	9960/77.3	.9996/7.31	.9997/4.4

Table 3.2 Reliability Growth legend: reliability/maintenance actions

3.3.9 Fill Rate Goal

Spare component levels are established to meet (or exceed) a stated fill rate goal. The fill rate goal is the fraction of demands (failures) which are immediately filled from on-hand serviceable stock. Figure 3.14 shows a slightly nonlinear trend as the fill rate goal is increased.

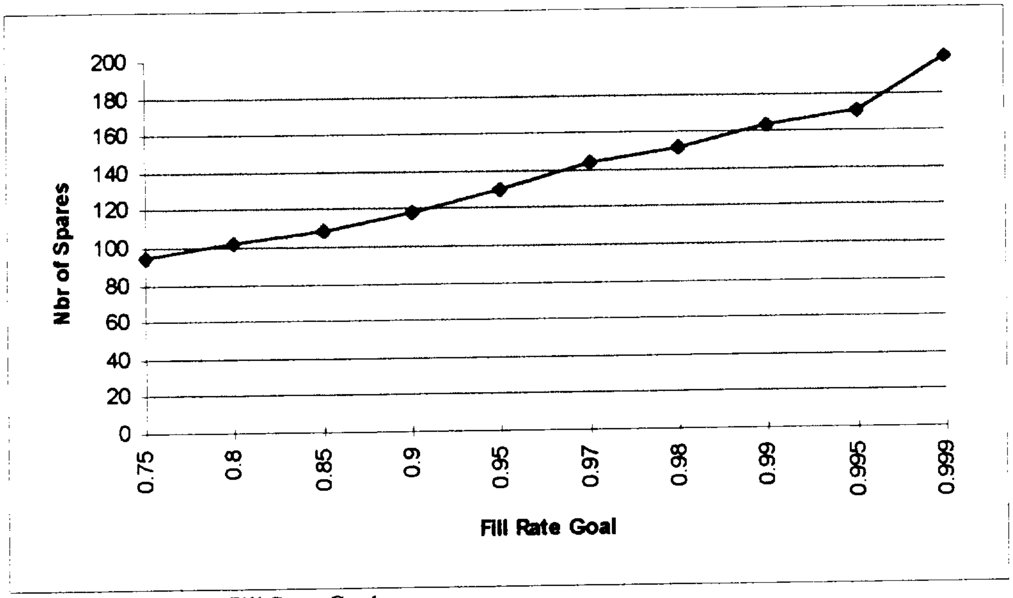


Figure 3.14 Fill Rate Goal

3.3.10 Mission Length

Increasing the duration of the mission will increase the number of maintenance actions, manpower, and spares as shown in Figure 3.15. Although the number of maintenance actions increases linearly, there is a slightly nonlinear effect with manpower and spares because integer values are computed. The manpower shown is based on the number of maintenance man-hours and not the assigned manpower.

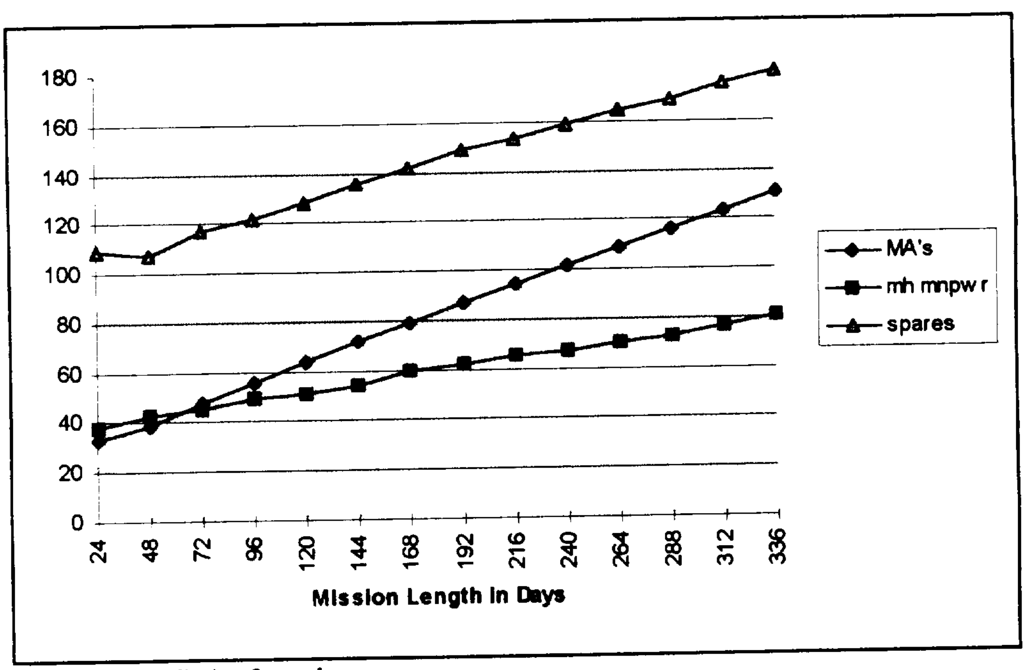


Figure 3.15 Mission Length

3.3.11 Fraction of Maximum Turntime

An average turntime is found by taking the weighted average of the maximum and minimum turntimes. The weight specified is the fraction of the maximum turntime. As expected, the effect of varying this weight is to shift linearly the turntime from the minimum to the maximum computed values.

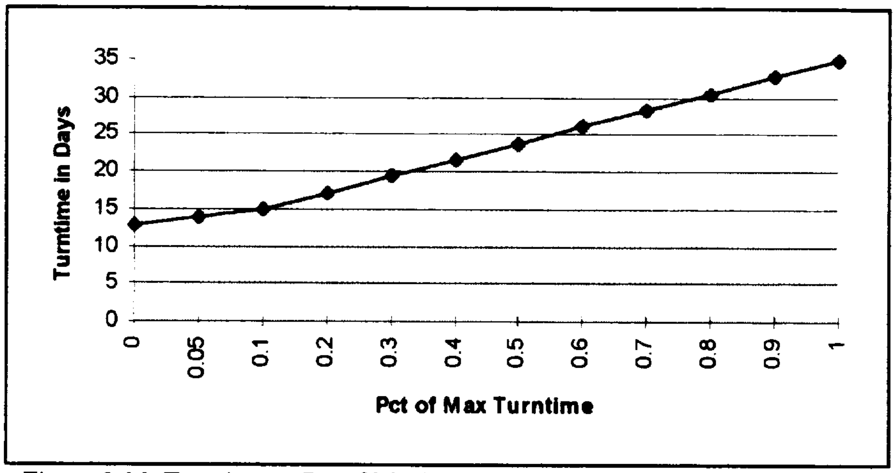


Figure 3.16 Turntime vs Pct of Maximum Turntime

3.3.12 Critical Failure Rate

The critical failure rate effects only the mission reliability. The critical failure rates shown in Figure 3.17 represent global values applied to all the subsystems. The results therefore will vary from the baseline case in which critical failure rates were individually assigned to subsystems. Nevertheless, the trend shown in the graph should be similar when plotting an average critical failure rate against the mission reliability. Missions reliability serious degrades at an overall critical failure of .004 or greater.

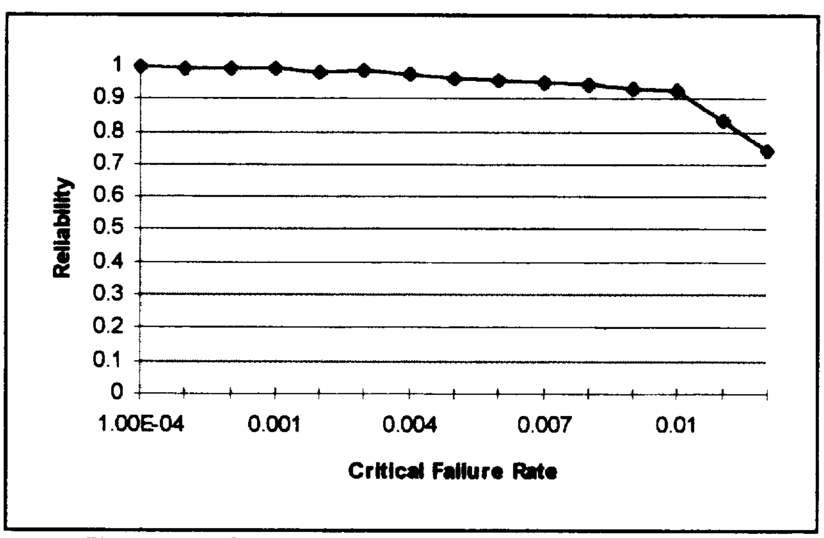


Figure 3.17 Critical Failure Rate

3.13 Removal Rate

Removal rates will only affect the number of spares computed to fill the resupply pipeline at the specified fill rate. There is a linear increase in the number of spares as the removal rate increases.

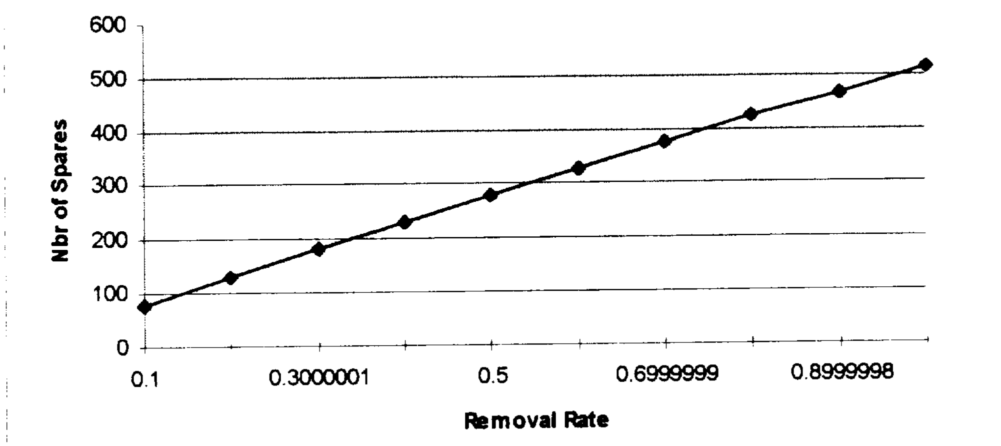


Figure 3.18 Removal Rate

3.14 Fraction Inherent Failures

The fraction of inherent failures is used to prorate the total number of maintenance actions between mission (inherent) and ground (externally induced) failures.

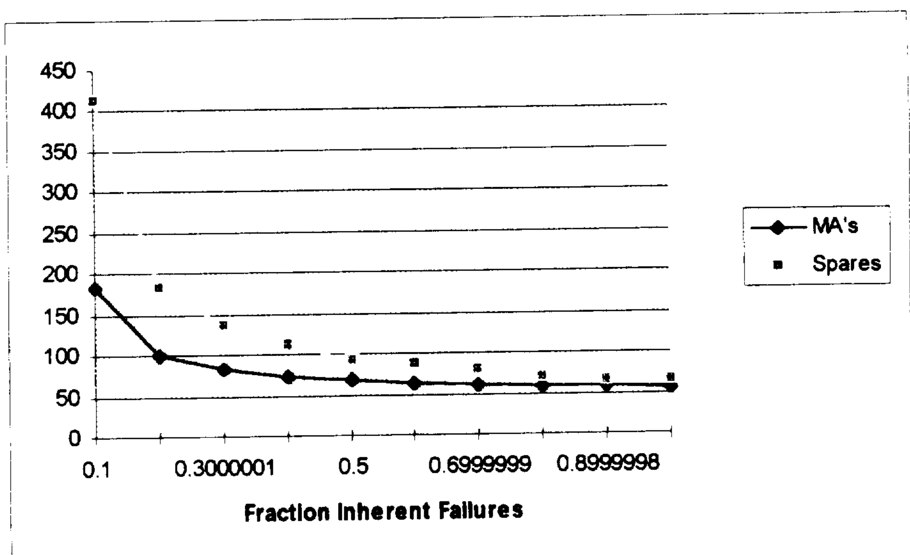


Figure 3.19 Fraction Inherent Failures

The relationship between this fraction and the reliability as measured by the number of maintenance actions is nonlinear. For aircraft type subsystems, as the fraction increases with all other parameters held constant, fewer inherent maintenance actions are generated since the following relationship must be satisfied:

$$\text{MA} \times \text{Fraction Inherent} = \text{Mission Hrs} / \text{MTBM}$$

where MTBM is the (space adjusted) mean time between inherent failures. Since spares are directly proportional to the number of maintenance actions, the spares curve has the same shape. Turntime, as shown in Figure 3.20, also experiences a similar improvement. For "shuttle" type subsystems, the number of maintenance actions will remain constant based upon the following:

$$\text{MA} = \text{total operating hrs} / \text{MTBM}$$

where the MTBM is an overall MTBM which includes both the ground and space environment. In this case, the inherent number of maintenance actions (MA x Fraction Inherent) will increase as the fraction increases although the total will not.

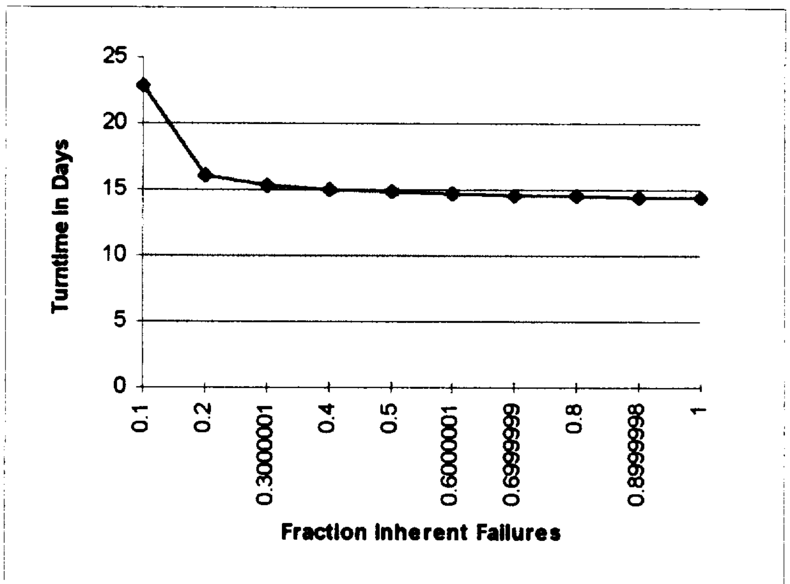


Figure 3.20 Fraction Inherent Failures vs Turntime

3.15 Technology Growth Rate

The technology growth rate depicted in Figure 3.21 is based upon a global value applied to all the subsystems. The nonlinear shape of the curve is as expected based upon the growth formula used:

$$\text{ADJ MTBM} = (1 + \text{growth rate})^{yrs}\ \text{MTBM}$$

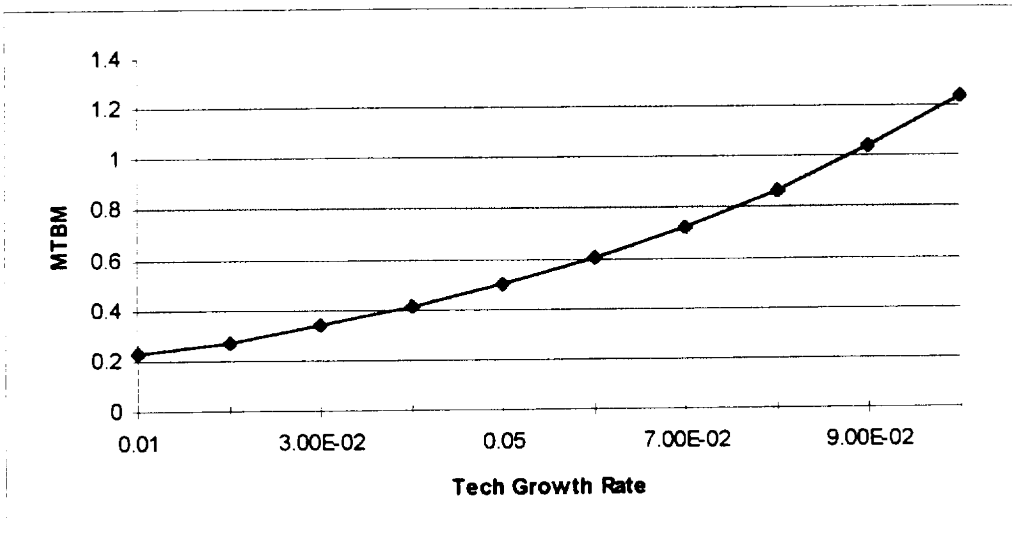


Figure 3.21 Technology Growth Rate

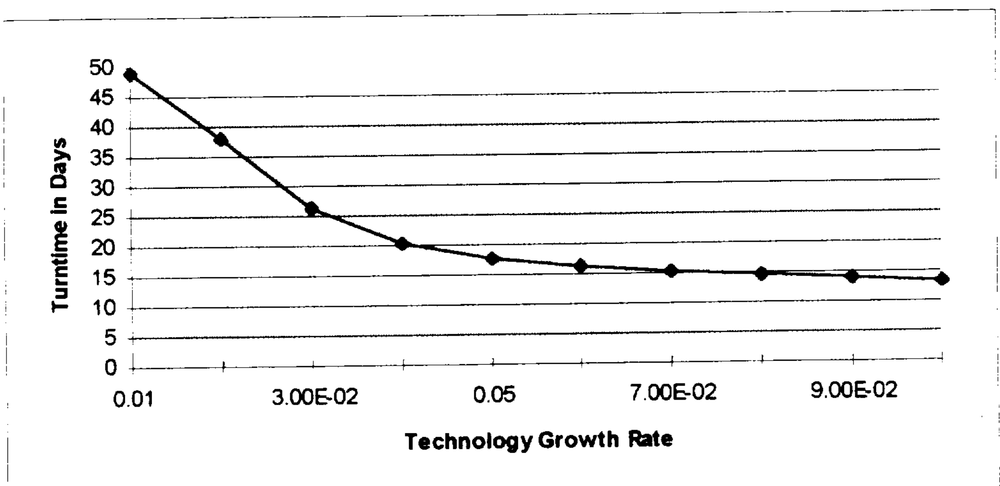


Figure 3.22 Growth Rate vs Turntime

Similar effects in growth rate can be observed in both the vehicle turntime and mission reliability as seen in Figures 3.22 and 3.23. As seen from these curves, significant improvement may be obtained by achieving growth rates of about 6 -7 percent. Increases beyond this value, while continuing to result in improved turntimes and reliability, do so with a much lower marginal values.

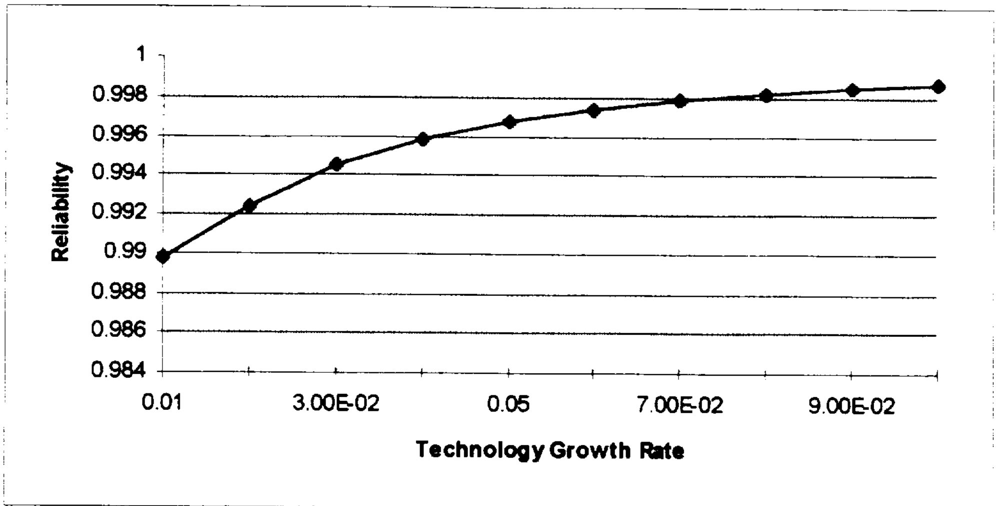


Figure 3.23 Growth Rate vs Reliability

4. Cost Analysis

In order to demonstrate the interaction between the Reliability and Maintainability Model (RAM) and the Operations and Support Costing (OSC) model, the OSC model was executed with the basecase input parameters and output values obtained from the RAM model. The remaining OSC parameters were based upon the default values. Both the input and output values are presented in Appendix E. Since the OSC model has not as yet been validated, the resulting costs should not be interpreted as actual costs. Rather the objective of this exercise is to demonstart the use of the cost model and to measure the sensitivity of the support costs to changes in vehicle design and performance measures in a relative sense.

For this analysis, all dollars are given as 1995 present values. Life cycle costs are based upon an eleven year vehicle life and a 3 percent discount rate. Initial beddown is assumed to be 2007 with two vehicles in the system having a combined mission rate of 30 missions per year. Logistics costs were based upon the Logistics Cost Model as modified in Chapter 2.[1] For the analysis which follows, the only operations cost addressed is the organizational maintenance cost (CES 2.3.1.2) since this is the only cost currently computed by the OSC model which is affected by the RAM parameters and output. As will also be seen, only certain logistics and support cost categories are impacted by the RAM model depending upon which parameters are changed within the model.

4.1 Reliability and Maintainability Sensitivity

Using the MTBM and MHMA calibration factors, systematic improvements were made to both reliability, as measured by the unadjusted MTBM, and the maintainability, as measured by the maintenance hours per maintenance action (MHMA). The basecase has default values of one except for LOX and LH2 tanks which have values of .8 for the MTBM factor. These factors were varied globally as shown in Table 4.1 with simultaneous improvements assumed for both reliability and maintainability until the reliability was doubled and the maintainability halved.

MTBM	MTTR	Orgn	Depot	Spares	Expend	Warehse	ILS mgt	Sys Spt	Total
1	1	12.734	.021	14.091	.071	.607	17.027	91.807	136.358
1.2	.9	12.434	.016	11.989	.055	.516	16.85	91.77	133.63
1.5	.8	11.975	.012	10.287	.042	.443	16.707	91.714	131.18
1.75	.7	11.618	.010	8.788	.035	.378	16.581	91.671	129.081
2	.5	11.364	.009	8.187	.030	.353	16.531	91.640	128.114

Table 4.1 Annual Operations and Support Costs in Millions of Dollars.

Figure 4.1 compares the differences in the costs of organizational maintenance and spares support as R&M improves. These costs were obtained by subtracting the corresponding cost of the cheapest case (case 5 in which reliability was doubled and maintainability halved) from the cost of each of the remaining cases. Therefore the relative cost on the vertical axis

[1] The alternate method of determining many of the logistics and support costs is based upon the hypervelocity life cycle cost model.

represents the net increase in cost from a baseline (case 5). Figure 4.2 was constructed in the same manner for secondary cost categories in which the cost increases were not as significant. In summary, a total cost savings of over 8 million dollars a year would be observed if the reliability were doubled and maintainability halved.

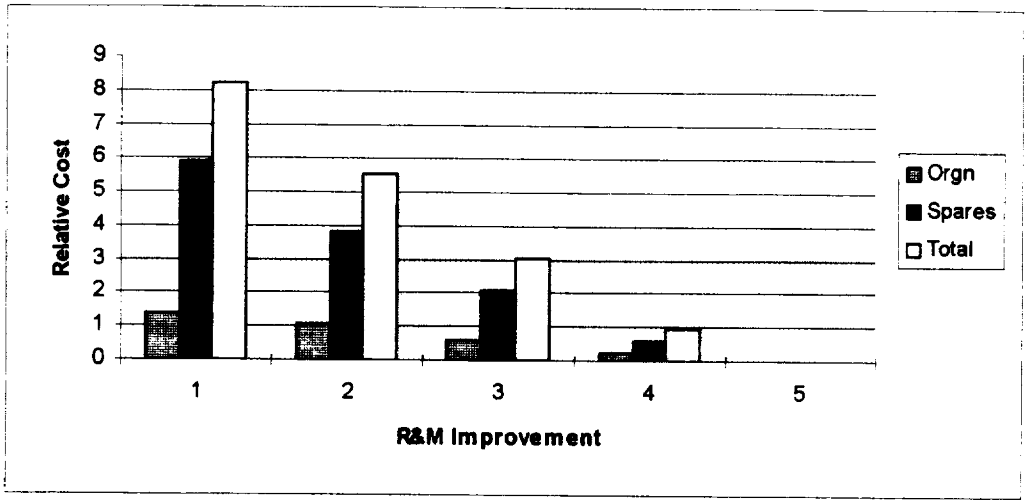


Figure 4.1 Primary Cost Savings

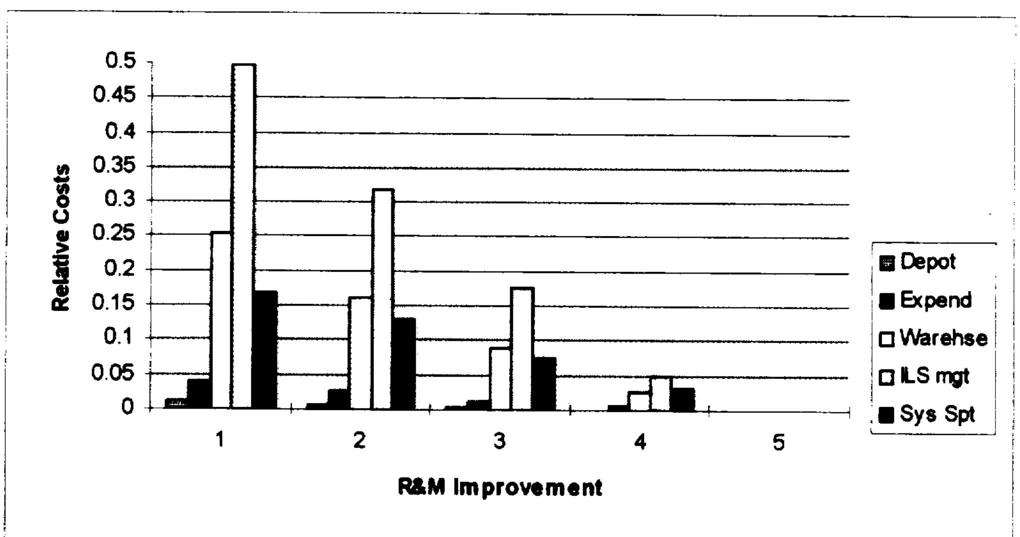


Figure 4.2 Secondary Cost Savings

4.2 Mission rate

Increasing the number of missions flown per year will obviously drive an increase in support cost. To quantify this increase the mission rate was varied from 20 missions per year to 60 missions per year with the following costs observed. The cost categories shown in Table 4.2 are those which are sensitive to the increase in the mission rate.

MSN/YR	ORN MNT	LOG SPT	SYS SPT	TOTAL
20	11.873	167.624	90.069	289.566
25	12.383	188.1	90.988	316.471
30	**12.739**	**208.129**	**91.807**	**342.675**
35	13.096	228.83	92.565	369.491
40	13.606	249.194	93.292	396.092
45	13.911	269.84	95.079	423.83
50	14.625	289.616	104	458.241
60	18.192	330.081	96.169	504.442

Table 4.2 Costs ($ M) versus Missions per Year

In each case, the system requires two vehicles in order to maintain the flight rate. At a flight rate of 60 missions per year, additional maintenance crews was assigned beyond the minimum number required to meet the manhour requirements. In order to maintain 60 missions per year, the turnaround time which was 12 days had to be reduced to under 11 days. This required adding 48 personnel to the minimum requirement. The curve would continue to increase in a nonlinear fashion as long as the requirement to keep the fleet size at two vehicles was maintained.

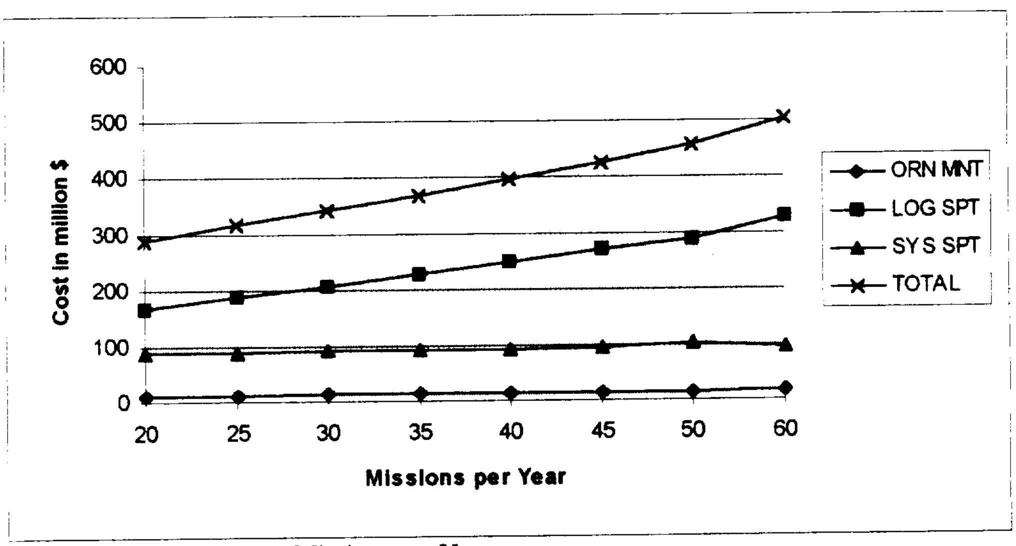


Figure 4.3 Costs versus Missions per Year

4.3 Weight Change

To measure the sensitivity of logoistics costs to changes in vehicle weight, the RAM model was utilized with various weight factors applied against the baseline weight of 174,160 pounds. For each factor, the model was recomputed and the results passed to the costing model (OSC). Shown below in Table 4.3 are the resulting costs which are then graphed in Figure 4.4.

Wgt Fac	Log Spt Cost ($ M)
0.6	179.96
0.8	188.898
1	**208.129**
1.2	227.509
1.4	246.715
1.6	265.413

Table 4.3 Weight Sensitivity

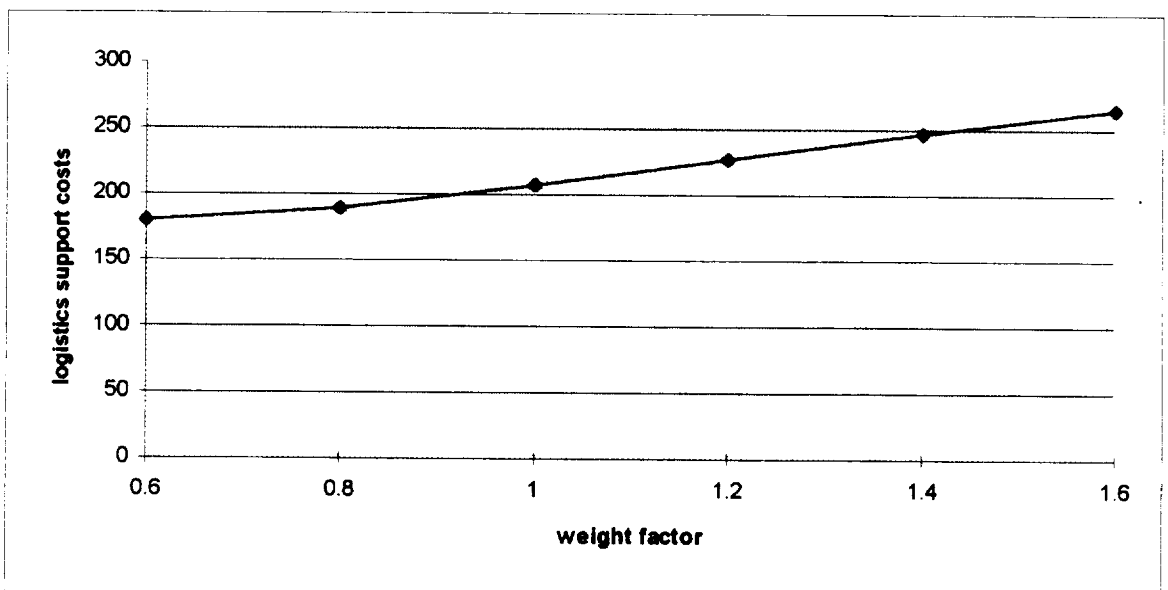


Figure 4.4 Weight Change versus Logistic Support Costs (in millions of dollars)

5. Conclusions

By applying the Reliability and Maintainability to a proposed space vehicle, several important improvements were identified and the resulting modifications made to the model. Collectively, these changes have improved considerably upon the study process. The more significant enhancements which affect the computed output values include: (1) improved R&M equations for the tank subsystems, (2) the ability to allocate schedule maintenance by subsystem, (3) redefined spares calculations, (4) computing a weighed average of the working days and mission days per month, and (5) the use of a position manning factor. Other modifications such as the addition of phase inspections and average turntimes provide additional capability. A third set of modifications provided greater flexibility of ease of use of model. These included the parametric analysis option, the application of the space adjustment feature by subsystem, weight parametric analysis, and the addition of the 34 subsystem.

The application of the revised model was illustrated by generating basecase R&M parameters for a proposed vehicle and then establishing the sensitivity of the R&M parameters and support costs to systematic changes in overall design or performance requirements. The sensitivity results are summarized qualitatively below:[1]

insensitive	moderate sensitivity	high sensitivity
vehicle dry weight	MTBM calibration factor	Mission length
Weibull shape parameter	MHMA calibration factor	Technology growth rate
Man-hour availability	Launch Factor	
Reliability Growth	Technology Year	
Fraction inherent failure	Fill Rate Goal	
	Critical Failure Rate	
	Removal rate	

Some parameters have a greater influence on support costs than on R&M parameters. A good example is vehicle dry weight. Although dry weight is a secondary "driver" variable for R&M parameters, it is a primary "driver" variable for certain types of support costs. Therefore, logistics support costs are vary sensitive to changes in overall vehicle weight. In general, changes in the design and performance parameters will affect the R&M parameters in predictable ways. Improvements in reliability (as measured by the MTBM) and maintainability (as measured by the MHMA or MTTR) will result in significant reductions in overall operations and support costs.

The use of the R&M model along with the companion Operations and Support Cost model have been demonstrated using a single conceptual vehicle. Further experience with both models should lead to additional improvements and enhancements. In the meantime, the R&M model should meet the objective of providing an initial estimate of the reliability and maintainability of a proposed space vehicle.

[1] This summary is by necessity highly subjective depending upon the range of values in which the parameter varies as well as the output parameter being measured.

Bibliography

1. *Advanced Manned Launch System Study (AMLS)*, Interim Review. Rockwell International Space Systems Division, Presented at Langley Research Center, Hampton, Va., NAS1-18975, June 4-5, 1991.

2. Albin and Kotker, *Conceptual Design and Analysis of Hypervelocity Aerospace Vehicles: Volume 5 - Cost*, AFWAL-TR-87-3056, BOEING Aerospace Co., Feb 1988.

3. Bloomquist, C. and W. Graham. *Analysis of Spacecraft On-orbit Anomalies and Lifetimes*. For Goddard Space Flight Center Contract No. NAS 5-27279. Los Angeles: PRC Systems Service, 1983.

4. Branscome, Darrell R., *NASA's Advanced Space Transportation System Launch Vehicles*, National Aeronautics and Space Administration, N91-28195, May 91.

5. Brussell, Pope, Tasugi, "Cost of Ownership-Industry Viewpoint Parametric Analysis of Operating and Support Costs", Proceedings 1975 Annual Reliability and Maintainability Symposium, 1975.

6. Dr. Callender and Steinbacher, *Information Life-Cycle and Documentation Standards*, release 4.3, NASA, Office of Safety, Reliability, Maintainability, and Quality Assurance/SMAP, Feb 1989.

7. Davies, Robert J. "Advanced Space Transportation Systems, Space Station Evolution Beyond the Baseline 1991", Presented at 2nd Symposium Evolution of SSF, N92-171104, September 1991.

8. *DoD Catalog of Logistics Models*, Defense Logistics Studies Information Exchange, Jan 1990.

9. Dotson, Raymon and Ernest Seaberg, "Logistics Analysis Model (LOGAM) Executive Summary", RCA/ Government and Commercial Sys, Feb. 1980.

10. Ebeling, Charles. *The Determination of Operational and Support Requirements and Costs During the Conceptual Design of Space Systems*. Final Report. Prepared for NASA Langley Research Center, Grant No. NAG1-1-1327, June 18, 1992.

11. Ebeling, Charles. *Enhanced Methods for Determining Operational Capabilities and Support Costs for Proposed Space Systems*. Prepared for NASA Langley Research Center, Grant No. NAG-1-1327, June 1993.

12. Ebeling, Charles. *Operations and Support Cost Modeling of Conceptual Space Vehicles*. Prepared for NASA Langley Research Center, Grant No. NAG-1-1327, June 1993 - July 1994.

13. Ebeling, Charles. *Integrating O&S Models During Conceptual Design - Parts I, II & III*. Prepared for NASA Langley Research Center, Grant No. NAG-1-1327, December 31, 1994.

14. Ebeling, Charles, *Reliability and Maintainability Model, User and Maintenance Manual,* Prepared for NASA Langley Research Center, Grant No. NAG-1-1327, December 31, 1995.

15. Forbis and Woodhead, *Conceptual Design and Analysis of Hypervelocity Aerospace Vehicles: Vol 3.* Cost, WL-TR-91-6003, Volume 3, BOEING Military Airplanes, Jul 1991.

16. Hess and Romanoff, *Aircraft Airframe Cost Estimating Relationships*, RAND, Dec 1987.

17. Isaacs, R., N. Montanaro, F. Oliver, *Modular Life Cycle Cost Model (MLCCM) for Advanced Aircraft Systems-Phase III, Vol VI*, Grumman Aerospace, Jun 1985.

18. Johnson, Vicki S.: *Life Cycle Cost in the Conceptual Design of Subsonic Aircraft.* Dissertation Submitted to the Department of Aerospace Engineering University of Kansas, October 12, 1988.

19. Kamrath, Knight, Quinn, Stamps, *PREVAIL: Algorithms for Conceptual Design of Space Transportation Systems*, Feb 1987.

20. Kasten, Terry D., "NASP: Enabling a New Space Launch Architecture". Presented at AIAA Space Programs and Technologies Conference, Huntsville, Al. AIAA 90-3833, 25-27 September 1990.

21. Keyworth, George A.; Abell, Bruce R. "How to Make Space Launch Routine". Technology Review, Vol 93, No 7, October 1990.

22. *Logistics Cost Analysis Model, Advanced Manned Launch System (AMLS)* Task Assignment 5 (September 10, 1993) and Task Number 15 (October 31, 1994), Rockwell International, Space Systems Division, Contract NAS1-19243 (NASA LRC).

23. Marks, Massey, Bradley, and Lu, *A New Approach to Modeling the Cost of Ownership for Aircraft Systems*, RAND, Aug 1981.

24. Morris, W.D. et. al., "Defining Support Requirements During Conceptual Design of Reusable Launch Vehicles," proceedings AIAA 1995 Space Programs and Technologies Conference, Huntsville, AL, September 1995.

25. O'Rourke, Joseph, J.; Whitman, Kenneth E.; Perkowski, Napoleon: *STS Ground Support System Study, Volume II, Vehicle and Facility Configurations.* AF-SAMSO-TR-72-56, March 1972.

26. Ross, Sheldon M. *Introduction to Probability and Statistics for Engineers and Scientists,* John Wiley and Sons, Inc., 1987.

27. *Space Systems Cost Study, Final Report.* Martin Marietta Astronautics Parametric Estimating System Department, March 1988.

APPENDIX A

LaRC Baseline
Access-to-Space Study
Single-Stage Vehicle Description
(DOS-12/15/93-Revised)

GENERAL VEHICLE DESCRIPTION

The design reference mission for the Access-to-Space Study (ATSS) single-stage vehicle (SSV) is to deliver to the Space Station Freedom (SSF) and return a 25-klb payload without crew when launched from the Eastern Test Range at the Kennedy Space Center (KSC). The Space Station Freedom is located in a 220-nmi circular orbit inclined 51.6 degrees to the equator. Four personnel, consumables, and refrigerated storage lockers could be accommodated in a pressurized SSF crew rotation module located in the forward portion of the payload bay. This same module would also be used, with minor modifications, for satellite servicing missions. The vehicle is designed to be flown in an unmanned mode. The payload bay is 15 ft in diameter and 30 ft long. On-board propellant would provide an incremental velocity (ΔV) of 1100 ft/sec following launch insertion into a 50 by 100 nmi orbit. Landing would nominally be at the KSC launch site.

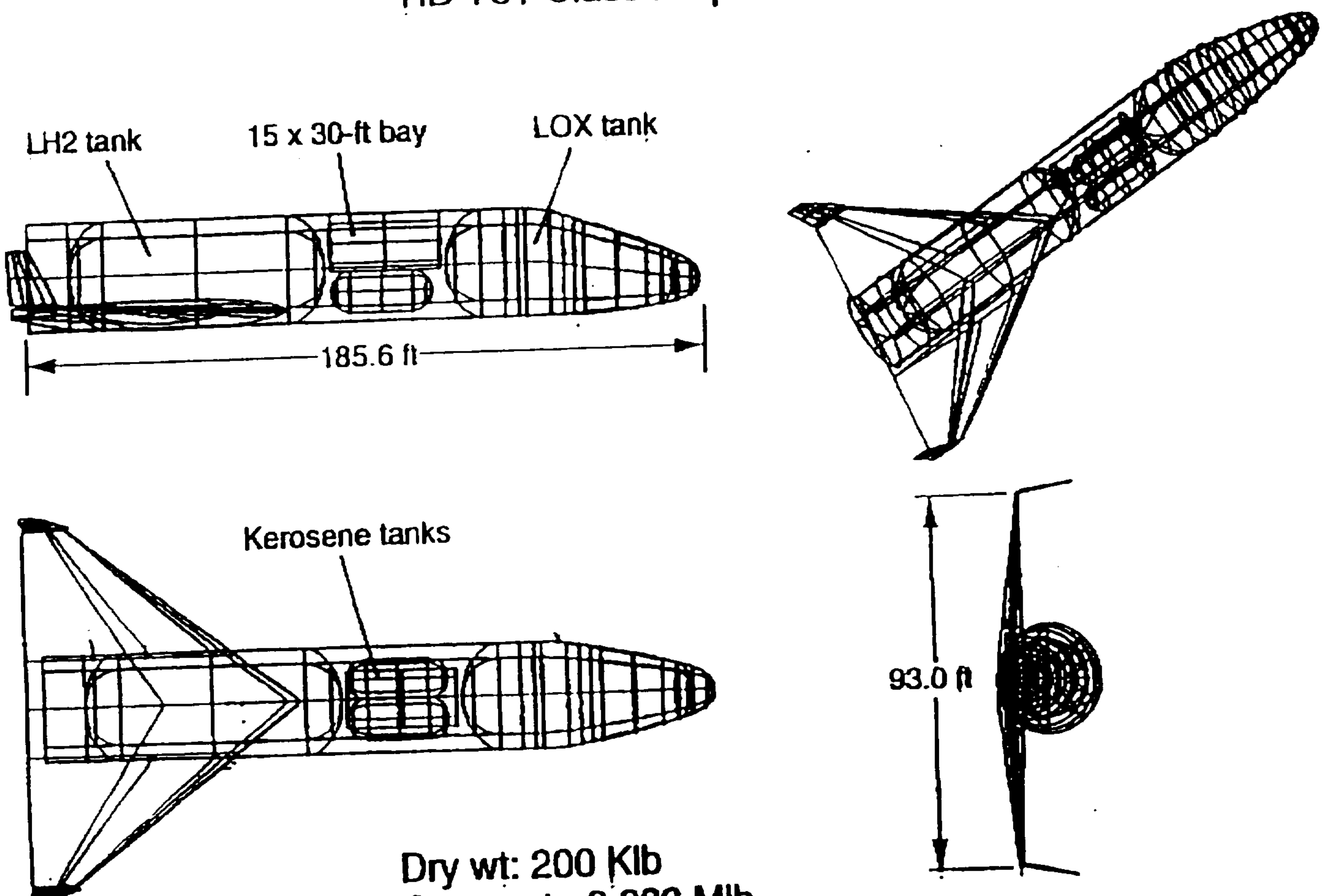
The SSV has a 1100-nmi crossrange capability to allow once-around abort for launch to a polar orbit and to increase daily landing opportunities to selected landing sites. The SSV also has a large range of intact abort opportunities in the event of a forced shutdown of a single main engine. Passenger escape is provided by ejection seats in the appropriate portions of the flight regime. All vehicle trajectories have maximum acceleration limits of 3 g and normal load constraints equivalent to a 2.5-g subsonic pull-up maneuver. In the design of the ATSS SSV, a 15-percent dry weight growth margin was allocated.

The reference vehicle is a vertical-takeoff, horizontal-landing winged concept with a circular-cross-section fuselage for structural efficiency. The payload bay is located between an aft liquid hydrogen (LH_2) tank and a forward liquid oxygen (LO_2) tank. The normal-boiling-point LH_2 and LO2 propellants are contained in integral, reusable cryogenic tanks. Two cylindrical hydrocarbon (RP-1) fuel tanks are located underneath the payload bay. The SSV main propulsion system uses seven tri-propellant engines to lower system dry weight. The vehicle employs wing tip fins for directional control rather than a single vertical tail. The vehicle employs a standardized payload canister concept with common interfaces to allow off-line processing of payloads and rapid payload integration. The lift-off thrust-to-weight ratio (T/W) of the SSV is 1.2. The total vehicle dry weight is 200,300 lb, and the gross weight is 2,383,000 lb. Evolutionary propulsion, structure, thermal protection system (TPS), and subsystem technologies are utilized that are consistent with an initial operating capability of 2007-2010.

LaRC 001 SSV CONFIGURATION

Dual-Fuel; 25 Klb to 220 n.mi and 51.6°

RD-701 Class Propulsion



Dry wt: 200 Klb

Gross wt: 2.383 Mlb

APPENDIX B
NASA Weight Statement
Unmanned Single Stage Vehicle (SSV)

conops.out Thu Apr 21 10:12:34 1994 1

WEIGHT STATEMENT - LEVEL III

unmanned ssv dual-fuel, rd-701, horz. 30 ft p/l bay, 25klb p/l - 51.6 inc.,

	WEIGHT (lb) LEVEL			CENTERS OF GRAVITY (ft./ft.)			MOM. OF INERTIA (slug-sq ft x10-6)		
	III	II	I	X/XREF	Y/YREF	Z/ZREF	XX	YY	ZZ
1.0 Wing			10823.	0.914	0.000	-0.020	0.225	0.062	0.283
Exposed wing surface		9281.		0.911	0.000	-0.019	0.222	0.060	0.278
Carry-through		1542.		0.936	0.000	-0.030	0.003	0.001	0.004
2.0 Tail			1902.	1.001	0.000	0.027	0.139	0.003	0.139
3.0 Body			62357.	0.588	0.000	0.026	0.298	5.119	5.098
LH2 tank		15781.		0.743	0.000	0.030	0.084	0.263	0.263
Structure	14029.			0.743	0.000	0.030	0.075	0.234	0.234
Insulation	1753.			0.743	0.000	0.030	0.009	0.029	0.029
Kerosene tank		2779.		0.468	0.000	-0.005	0.005	0.007	0.009
Structure	2779.			0.468	0.000	-0.005	0.005	0.007	0.009
Insulation	0.			0.468	0.000	-0.005	0.000	0.000	0.000
LO2 tank		12579.		0.224	0.000	0.024	0.054	0.150	0.150
Structure	11542.			0.224	0.000	0.024	0.050	0.137	0.137
Insulation	1037.			0.224	0.000	0.024	0.004	0.012	0.012
Basic and secondary structure		31218.		0.666	0.000	0.027	0.152	2.262	2.242
Nose section	461.			0.031	0.000	0.002	0.001	0.000	0.000
Intertank	6677.			0.462	0.000	0.030	0.042	0.070	0.070
Aft body/thrust structure	3630.			0.908	0.000	0.030	0.023	0.013	0.013
Thrust structure cone	6847.			0.935	0.000	0.030	0.029	0.016	0.016
Engine bay	1409.			0.968	0.000	0.030	0.009	0.005	0.005
Crew cabin, work station	0.			0.648	0.000	0.097	0.000	0.000	0.000
P/L bay doors	2100.			0.462	0.000	0.100	0.001	0.005	0.006
P/L bay/ker. tank support str.	6500.			0.462	0.000	-0.005	0.013	0.028	0.030
P/L container	1800.			0.462	0.000	0.064	0.003	0.008	0.008
Base heat shield str.	1043.			1.000	0.000	0.030	0.003	0.002	0.002
Body flap	751.			1.030	0.000	-0.043	0.003	0.000	0.003
4.0 Induced environment protection			19580.	0.619	0.000	0.013	0.209	1.831	1.934
TPS		17898.		0.632	0.000	0.015	0.200	1.678	1.781
Fuselage	13124.			0.530	0.000	0.028	0.078	1.095	1.095
Wing	4774.			0.911	0.000	-0.019	0.114	0.031	0.143
Internal insulation		968.		0.497	0.000	-0.001	0.003	0.060	0.057
Nose	156.			0.031	0.000	0.002	0.000	0.000	0.000
Payload bay doors	163.			0.462	0.000	0.100	0.000	0.000	0.000
Equipment bays	650.			0.618	0.000	-0.027	0.000	0.010	0.010
Purge, vent, drn, & hazrd gas det		713.		0.462	0.000	-0.020	0.005	0.056	0.058
5.0 Undercarriage and aux. systems			7018.	0.797	0.000	-0.028	0.036	0.232	0.267
Nose gear		1041.		0.376	0.000	-0.034	0.000	0.000	0.000
Running gear	198.			0.376	0.000	-0.034	0.000	0.000	0.000
Structure	766.			0.376	0.000	-0.034	0.000	0.000	0.000
Controls	77.			0.376	0.000	-0.034	0.000	0.000	0.000
Main gear		5977.		0.870	0.000	-0.027	0.036	0.000	0.036

Running gear	2421.			0.870	0.000	-0.027	0.014	0.000	0.014
Structure	3218.			0.870	0.000	-0.027	0.019	0.000	0.019
Controls	338.			0.870	0.000	-0.027	0.002	0.000	0.002
6.0 Propulsion, main			52929.	0.929	0.000	0.032	0.119	1.756	1.758
Engines		40742.		0.989	0.000	0.030	0.097	0.050	0.053
Press and feed		9797.		0.806	0.000	0.046	0.016	0.682	0.683
Helium pnuematic & purge system		2390.		0.408	0.000	0.006	0.003	0.010	0.012
7.0 Propulsion, reaction control (RCS)			3626.	0.611	0.000	-0.012	0.017	0.223	0.220
Thrusters and supports		507.		0.879	0.000	0.028	0.002	0.041	0.043
Fwd	48.			0.022	0.000	0.014	0.000	0.000	0.000
Aft	460.			0.968	0.000	0.030	0.002	0.000	0.002
Propellant tanks		1241.		0.468	0.000	-0.023	0.000	0.000	0.000
Distribution & recirculation		1309.		0.634	0.000	-0.016	0.010	0.079	0.076
Valves		569.		0.634	0.000	-0.016	0.004	0.034	0.033
8.0 Propulsion, orbital maneuver (OMS)			2276.	0.595	0.000	0.046	0.007	0.124	0.131
Engines		545.		0.996	0.000	0.063	0.002	0.000	0.002
Propellant tanks		740.		0.468	0.000	0.041	0.005	0.000	0.004
Pressurization		991.		0.468	0.000	0.041	0.000	0.000	0.000
9.0 Prime power			2339.	0.365	0.000	0.087	0.000	0.000	0.000
Fuel cell system		2324.		0.365	0.000	0.087	0.000	0.000	0.000
Cells	888.			0.365	0.000	0.087	0.000	0.000	0.000
Reactant dewars	1436.			0.365	0.000	0.087	0.000	0.000	0.000
Batteries		15.		0.365	0.000	0.087	0.000	0.000	0.000
10.0 Electric conversion and distr.			6331.	0.447	0.000	0.042	0.014	0.275	0.309
Power conversion and distr.		1705.		0.365	0.000	0.087	0.002	0.050	0.051
Circuitry		4199.		0.431	0.000	0.029	0.006	0.092	0.131
Elect. pwr dist & cntrl	1355.			0.409	0.000	0.030	0.002	0.004	0.041
Avionic cabling	1908.			0.409	0.000	0.030	0.003	0.065	0.066
RCS cabling	62.			0.500	0.000	0.000	0.000	0.000	0.000
OMS cabling	193.			0.661	0.000	0.030	0.001	0.000	0.001
Connector plates	207.			0.462	0.000	0.030	0.000	0.005	0.005
Wire trays	474.			0.462	0.000	0.030	0.001	0.004	0.005
Electromech. act. (EMA) cabling		103.		0.796	0.000	0.005	0.001	0.000	0.000
EMA control units		324.		0.984	0.000	-0.008	0.000	0.000	0.000
11.0 Hydraulic conversion and distr.			0.	0.000	0.000	0.000	0.000	0.000	0.000
12.0 Control surface actuation			1285.	0.988	0.000	-0.011	0.062	0.001	0.062
Elevons		746.		0.997	0.000	-0.017	0.041	0.000	0.041
Tip fins		291.		0.997	0.000	0.024	0.021	0.000	0.021
Body flap		248.		0.952	0.000	-0.032	0.000	0.000	0.000
13.0 Avionics + Health Monitoring			1314.	0.178	0.000	0.023	0.006	0.166	0.165
Guid., nav., & contrl.		248.		0.376	0.000	0.068	0.001	0.034	0.034
Comm. & tracking		377.		0.024	0.000	-0.012	0.001	0.008	0.008
Displays & contrl.		0.		0.462	0.000	0.064	0.000	0.000	0.000
Instrum. system		361.		0.024	0.000	-0.012	0.001	0.047	0.047
Data processing		328.		0.376	0.000	0.068	0.001	0.032	0.033
14.0 Environmental control			2395.	0.450	0.000	0.056	0.011	0.129	0.127
Personnel system		0.		0.640	0.000	0.100	0.000	0.000	0.000
Equipment cooling		559.		0.376	0.000	0.078	0.001	0.034	0.034
Heat transport loop		1265.		0.462	0.000	0.030	0.008	0.086	0.086
Heat rejection system		571.		0.498	0.000	0.093	0.000	0.002	0.002
Radiators	362.			0.462	0.000	0.100	0.000	0.001	0.001
Flash evaporator system	208.			0.560	0.000	0.082	0.000	0.000	0.000

15.0 Personnel provisions			0.	0.000	0.000	0.000	0.000	0.000	0.000
Food, waste, & water mngmt.		0.		0.640	0.000	0.100	0.000	0.000	0.000
Seats		0.		0.640	0.000	0.100	0.000	0.000	0.000
18.0 Payload provisions			0.	0.000	0.000	0.000	0.000	0.000	0.000
19.0 Margin			26126.	0.718	0.000	0.022	0.182	2.405	2.480
EMPTY			200300.	0.718	0.000	0.022	1.398	18.504	19.080
20.0 Personnel			0.	0.000	0.000	0.000	0.000	0.000	0.000
Crew & gear		0.		0.640	0.000	0.100	0.000	0.000	0.000
Accessories		0.		0.462	0.000	0.064	0.000	0.000	0.000
21.0 Payload accomodations			0.	0.462	0.000	0.064	0.000	0.000	0.000
22.0 Payload			25000.	0.462	0.000	0.064	0.022	0.069	0.069
23.0 Residual and unusable fluids			13047.	0.748	0.000	0.046	0.023	1.081	1.076
Ascent		10986.		0.806	0.000	0.046	0.022	0.823	0.820
OMS		881.		0.468	0.000	0.031	0.000	0.000	0.000
RCS		587.		0.468	0.000	0.031	0.000	0.000	0.000
Subsystems		592.		0.365	0.000	0.087	0.000	0.000	0.000
25.0 Reserve fluids			7290.	0.494	0.000	0.008	0.017	0.446	0.446
Ascent		5911.		0.500	0.000	0.008	0.012	0.443	0.441
OMS		618.		0.468	0.000	0.041	0.004	0.000	0.004
RCS		762.		0.468	0.000	-0.023	0.000	0.000	0.000
26.0 Inflight losses			3804.	0.473	0.000	0.082	0.001	0.038	0.038
Fuel cell reactants		1612.		0.365	0.000	0.087	0.000	0.000	0.000
Evaporator water supply		2083.		0.560	0.000	0.082	0.000	0.000	0.000
Helium supply		110.		0.408	0.000	0.006	0.000	0.000	0.000
27.0 Propellant, main			2143859.	0.294	0.000	0.022	5.278	67.865	67.799
Start-up		32127.		0.292	0.000	0.022	0.079	0.912	0.911
LH2	1928.			0.743	0.000	0.030	0.006	0.024	0.024
Kerosene	4048.			0.468	0.000	-0.005	0.005	0.007	0.011
LO2	26151.			0.231	0.000	0.025	0.064	0.218	0.217
Ascent		2111732.		0.294	0.000	0.022	5.199	66.953	66.887
LH2	165237.			0.743	0.000	0.030	0.477	2.067	2.067
Kerosene	207481.			0.468	0.000	-0.005	0.278	0.363	0.551
LO2	1739014.			0.231	0.000	0.025	4.256	14.498	14.431
28.0 Propellant, reaction control			2887.	0.468	0.000	-0.023	0.015	0.321	0.329
Orbital propellant		2192.		0.468	0.000	-0.023	0.012	0.244	0.250
Entry propellant		695.		0.468	0.000	-0.023	0.004	0.077	0.079
29.0 Propellant, orbital maneuver			19372.	0.468	0.000	0.041	0.120	0.000	0.117
PRELAUNCH GROSS			2415560.	0.336	0.000	0.023	6.958	127.258	127.803
			0.	0.000	0.000	0.000	0.000	0.000	0.000
Prelaunch gross			2415560.	0.336	0.000	0.023	6.958	127.258	127.803
Start-up losses			-32127.	0.292	0.000	0.022	-0.079	-0.912	-0.911
LH2		-1928.		0.743	0.000	0.030	-0.006	-0.024	-0.024
Kerosene		-4048.		0.468	0.000	-0.005	-0.005	-0.007	-0.011
LO2		-26152.		0.231	0.000	0.025	-0.064	-0.218	-0.217
Gross lift-off			2383432.	0.337	0.000	0.023	6.879	126.277	126.823
Ascent propellant			-2111732.	0.294	0.000	0.022	-5.199	-66.953	-66.887
LH2		-165237.		0.743	0.000	0.030	-0.477	-2.067	-2.067
Kerosene		-207481.		0.468	0.000	-0.005	-0.278	-0.363	-0.551
LO2		-1739014.		0.231	0.000	0.025	-4.256	-14.498	-14.431
Insertion			271700.	0.666	0.000	0.028	1.671	23.648	24.269
Ascent reserves			-5911.	0.500	0.000	0.008	-0.012	-0.443	-0.441
Ascent residuals			-10986.	0.806	0.000	0.046	-0.022	-0.823	-0.820

Inflight losses			-3804.	0.473	0.000	0.082	-0.001	-0.038	-0.038
Fuel cell reactants		-1612.		0.365	0.000	0.087	0.000	0.000	0.000
Evaporator water supply		-2083.		0.560	0.000	0.082	0.000	0.000	0.000
Helium supply		-110.		0.408	0.000	0.006	0.000	0.000	0.000
Aux. propulsion propellant			-21565.	0.468	0.000	0.034	-0.140	-0.252	-0.367
RCS		-2192.		0.468	0.000	-0.023	-0.012	-0.244	-0.250
OMS		-19372.		0.468	0.000	0.041	-0.120	0.000	-0.117
Payload delivered			-25000.	0.462	0.000	0.064	-0.022	-0.069	-0.069
Payload accepted			25000.	0.462	0.000	0.064	0.022	0.069	0.069
Entry			229434.	0.686	0.000	0.027	1.477	20.514	21.046
RCS prop. (entry)			-695.	0.468	0.000	-0.023	-0.004	-0.077	-0.079
Landed			228740.	0.686	0.000	0.027	1.471	20.399	20.931
Payload (returned)			-25000.	0.462	0.000	0.064	-0.022	-0.069	-0.069
Landed (p/l out)			203740.	0.714	0.000	0.022	1.407	18.775	19.349
Personnel			0.	0.000	0.000	0.000	0.000	0.000	0.000
Crew & gear		0.		0.640	0.000	0.100	0.000	0.000	0.000
Accessories		0.		0.462	0.000	0.064	0.000	0.000	0.000
Payload accomodations			0.	0.462	0.000	0.064	0.000	0.000	0.000
Subsystem residuals			-592.	0.365	0.000	0.087	0.000	0.000	0.000
Aux. propulsion residuals			-1468.	0.468	0.000	0.031	0.000	0.000	0.000
OMS		-881.		0.468	0.000	0.031	0.000	0.000	0.000
RCS		-587.		0.468	0.000	0.031	0.000	0.000	0.000
Aux. propulsion reserves			-1380.	0.468	0.000	0.006	-0.005	-0.001	-0.004
OMS		-618.		0.468	0.000	0.041	-0.004	0.000	-0.004
RCS		-762.		0.468	0.000	-0.023	0.000	0.000	0.000
Empty			200300.	0.718	0.000	0.022	1.398	18.504	19.080
			0.	0.000	0.000	0.000	0.000	0.000	0.000
FLUIDS INVENTORY			0.	0.000	0.000	0.000	0.000	0.000	0.000
LH2			172655.	0.000	0.000	0.000	0.000	0.000	0.000
Main propulsion		168656.		0.000	0.000	0.000	0.000	0.000	0.000
Start-up	1928.			0.000	0.000	0.000	0.000	0.000	0.000
Ascent	165237.			0.000	0.000	0.000	0.000	0.000	0.000
Reserve	832.			0.000	0.000	0.000	0.000	0.000	0.000
Residual	659.			0.000	0.000	0.000	0.000	0.000	0.000
OMS		2982.		0.000	0.000	0.000	0.000	0.000	0.000
RCS		847.		0.000	0.000	0.000	0.000	0.000	0.000
Fuel cell		170.		0.000	0.000	0.000	0.000	0.000	0.000
Kerosene			212914.	0.000	0.000	0.000	0.000	0.000	0.000
Main propulsion		212914.		0.000	0.000	0.000	0.000	0.000	0.000
Start-up	4048.			0.000	0.000	0.000	0.000	0.000	0.000
Ascent	207481.			0.000	0.000	0.000	0.000	0.000	0.000
Residual	1384.			0.000	0.000	0.000	0.000	0.000	0.000
LO2			1801907.	0.000	0.000	0.000	0.000	0.000	0.000
Main propulsion		1779186.		0.000	0.000	0.000	0.000	0.000	0.000
Start-up	26152.			0.000	0.000	0.000	0.000	0.000	0.000
Ascent	1739014.			0.000	0.000	0.000	0.000	0.000	0.000
Reserve	5078.			0.000	0.000	0.000	0.000	0.000	0.000
Residual	8943.			0.000	0.000	0.000	0.000	0.000	0.000
OMS		17890.		0.000	0.000	0.000	0.000	0.000	0.000
RCS		3389.		0.000	0.000	0.000	0.000	0.000	0.000
Fuel cell		1442.		0.000	0.000	0.000	0.000	0.000	0.000
Evaporator water			2083.	0.000	0.000	0.000	0.000	0.000	0.000

Helium	110.	0.000	0.000	0.000	0.000	0.000	0

* INDICATES WEIGHT IS NOT WITHIN LIMITS OF WEIGHT EQUATION

unmanned ssv dual-fuel, rd-701, horz. 30 ft p/l bay, 25klb p/l - 51.6 inc.,

DESIGN DATA

number of landing gear wheels	10.0000
number of aerosurface actuators	7.0000
number of landing gear actuators	3.0000
number of TVC actuators	14.0000
number of control surfaces	7.0000
number of propellant tanks	4.0000
number of crew	0.0000
required peak fuel cell power (kw)	240.0000
total electric power (kva)	240.0000
total cooling capacity (kw)	15.3000
total cooling capacity (btu/hr/1000)	52.2000
payload volume (cu. ft.)	5300.0000
payload weight (lb)	25000.0000
lift-off t/w ratio	1.2000
landing gear height (ft)	13.9730
total vehicle length (ft)	193.4257
body_length_______________ft_	185.6408
body_width________________ft_	28.5831
body_height_______________ft_	28.5831
body_volume____________cu_ft_	105712.4688
body_tps_wetted_area___sq_ft_	15563.9063
wing_tps_wetted_area___sq_ft_	5067.3770
body flap length (ft)	8.1343
tip fins (2) planform area (ft2)	271.5986

SIZING PARAMETERS

Mass ratio	8.7723
Propellant mass fraction	0.8860
Body length (ft.)	185.6
Wing span (ft.)	93.0
Theoretical wing area (sq. ft.)	4192.2
Wing loading at design wt (psf)	54.6
Wing planform ratio, sexp/sref	0.58
Sensitivity of volume to burnout wt (cu. ft./klb.)	383.9
Burnout weight growth factor (lb/lb)	2.6

	BODY	WING
Total volume (cu. ft.)	105712.	13373.
Tank volume (cu. ft.)	68888.	0.
Fixed volume (cu. ft.)	0.	0.
Tank efficiency factor	0.6517	0.0000
Ullage volume fraction	0.0300	0.0300

PROPELLANT		FRACTION	DENSITY (lb/cu. ft.)	FLUID VOLUME (cu. ft.)	TANK VOLUME (cu. ft.)
lh2		0.0782	4.42	37384.	38990.
hc		0.0983	50.50	4109.	4318.
lox		0.8235	71.14	24445.	25580.
lox	(Wing)	0.0000	71.14	0.	0.

APPENDIX C
BASECASE INPUT PARAMETERS AND VALUES

A. SYSTEM PARAMETER VALUES

PARAMETER	VALUE
DRY WGT (LBS)	174160
LENGTH (FT)	185.6
WING SPAN	93
CREW SIZE	0
NBR PASSENGERS	0
NBR MAIN ENGINES	7
ADJ SHUTTLE MTBM-SPACE 0-NO 1-YES	0
TECHNOLOGY YR	2007
DEFAULT ABORT RATE	.001
WIEBULL SHAPE PARAMETER	.28
LAUNCH FACTOR	20
AVAIL MANHRS/MONTH	144
FRACTION INDIRECT WORK	.15
SPARE FILL RATE OBJ	.95
MANPWR FOR PAD OPER	20
PLANNED MISSIONS/YEAR	30
MODE INDICATOR	2
VEHICLE INTEGRATION TIME (DAYS)	0
LAUNCH PAD TIME (DAYS)	.5
AGGREGATE AVIONICS 0-NO/1-YES	0
TURNTIME PRORATION-FRACTION OF MAX	.1
NBR RCS ENGINES	1
NBR OMS ENGINES	1
GROWTH CURVE SLOPE	.5
MSN NBR FOR REL GROWTH	1
AIR+GND ABORTS-0 / AIR ABORTS-1	1
Depot LRU TAT in days	70

B. SECONDARY VARIABLE VALUES

VARIABLE	VALUE
FUSELAGE AREA	15564
FUSELAGE VOLUME	105712
WETTED AREA	20631
NBR WHEELS	10
NBR ACTUATORS	7
NBR CONTR SURFACES	7
KVA MAX	240
NBR HYDR SUBSYS	1
NBR FUEL TANKS (INTERNAL)	2
TOT NBR AVIONICS SUBSYS	5
NBR DIFF AVIONICS SUBSYS	5
BTU COOLING	52.2
NBR OXIDIZER TANKS	1

C. SUBSYSTEM WEIGHTS & CALIBRATION FACTORS

WBS	WEIGHT	MTBM FAC	MH/MA FACTOR
1.00 WING GROUP	10823	1	1
2.00 TAIL GROUP	1902	1	1
3.00 BODY GROUP	31218	1	1
3.10 TANKS-LOX	12579	.8	1
3.20 TANKS-LH2	15781	.8	1
4.10 IEP-TILES	17898	1	1
4.20 IEP-TCS	968	1	1
4.30 IEP-PVD	713	1	1
5.00 LANDING GEAR	7018	1	1
6.00 PROPULSION-MAIN	40742	1	1
7.00 PROPULSION-RCS	3626	1	1
8.00 PROPULSION-OMS	2276	1	1
9.30 POWER-FUEL CELL	2324	1	1
10.00 ELECTRICAL	6331	1	1
12.00 AERO SURF ACTUATORS	1285	1	1
13.10 AVIONICS-GN&C	248	1	1
13.20 AV-HEALTH MONITOR	1	1	1
13.30 AVIONICS-COMM & TRACK	377	1	1
13.50 AVIONICS-INSTRUMENTS	361	1	1
13.60 AVIONICS-DATA PROC	328	1	1
14.10 ENVIRONMENTAL CONTROL	2395	1	1
3.30 TANKS-RP	2779	1	1
6.10 PROPULSION-MPS	12187	1	1

TOTAL WEIGHT 174160 WEIGHT FACTOR IS 1

D. SUBSYSTEM OPERATING HOURS

SUBSYSTEM	PROCESS TIME	PAD TIME	BOOST TIME	RE TIME TO-ORBIT	ORBIT TIME	REENTRY TIME
1.00 WING GROUP	10	0	.14	.86	167	1
2.00 TAIL GROUP	10	0	.14	.86	167	1
3.00 BODY GROUP	10	0	.14	.86	167	1
3.10 TANKS-LOX	10	0	.14	.86	167	1
3.20 TANKS-LH2	10	0	.14	.86	167	1
4.10 IEP-TILES	10	0	.14	.86	167	1
4.20 IEP-TCS	10	0	.14	.86	167	1
4.30 IEP-PVD	10	0	.14	.86	167	1
5.00 LANDING GEAR	1	0	0	0	0	1
6.00 PROPULSION-MAIN	10	0	.14	0	0	0
7.00 PROPULSION-RCS	10	0	.01	.1	.5	.1
8.00 PROPULSION-OMS	10	0	.01	.25	.1	.1
9.30 POWER-FUEL CELL	10	4	.14	.86	167	1
10.00 ELECTRICAL	10	12	.14	.86	167	1
12.00 AERO SURF ACT	10	0	.14	.86	167	1
13.10 AVIONICS-GN&C	10	4	.14	.86	167	1
13.20 AV-HEALTH MONITOR	10	4	.14	.86	167	1
13.30 AVIONICS-COMM/TR	10	4	.14	.86	167	1
13.50 AVIONICS-INST	10	4	.14	.86	167	1
13.60 AVIONICS-DATAPROC	10	4	.14	.86	167	1
14.10 ENVIRONMENTAL CON	10	4	.14	.86	167	1
3.30 TANKS-RP	10	0	.14	.86	167	1
6.10 PROPULSION-MPS	10	0	.14	0	0	0

E. SUBSYSTEM COMPUTATION FACTORS

SUSBSYTEM	TECH GRWTH FACTOR	CRITICAL FAIL RATE	REMOVAL RATE	FRACTION OFF EQUIP
1.00 WING GROUP	.082	1.942436E-04	.1923022	.0835
2.00 TAIL GROUP	.082	1.942436E-04	.1923022	.0835
3.00 BODY GROUP	.082	1.575159E-04	.2229133	.0857
3.10 TANKS-LOX	.041	.0001	.2758	0
3.20 TANKS-LH2	.041	.0001	.2758	0
4.10 IEP-TILES	.082	.00065	.001	0
4.20 IEP-TCS	.082	.00065	.481	0
4.30 IEP-PVD	.082	.00065	.391	0
5.00 LANDING GEAR	.033	4.987509E-04	.22	.27599
6.00 PROP-MAIN	.011	.00065	.555609	.725
7.00 PROP-RCS	.011	.00065	.5975044	.725
8.00 PROP-OMS	.011	.00065	.5968578	.725
9.30 PWR-FUEL CELL	.056	.00065	.261	0
10.00 ELECTRICAL	0	.00031	.5007281	.21081
12.00 AERO SUR ACT	.056	4.331814E-04	.38593	.29
13.10 AV-GN&C	.11	.0033	.4	.532
13.20 AV-HLTH MON	.11	.001	.4147191	.532
13.30 AV-COMM/TRK	.11	.0012925	.4	.532
13.50 AV-INSTR	.11	.0024	.51	.44
13.60 AV-DATA PROC	.11	.001	.4147191	.532
14.10 ENV CNTRL	.0062	.0004408	.5151376	.0932
3.30 TANKS-RP	.041	.0001	.164	0
6.10 PROP-MPS	.011	.00065	.555609	.725

Notes: 1. CRITICAL FAILURE RATE - fraction of total maintenance actions resulting in a mission abort.

2. REMOVAL RATE - probability of a removal per maintenance action.

3. FRACTION OFF VEHICLE - fraction of total maintenance manhours performed off the vehicle - does not impact vehicle turntime.

F. ADDITONAL SUBSYSTEM COMPUTATION FACTORS

SUSBSYTEM	CREW SIZE	NBR CREWS ASGN	FRACTION INHERENT FAILURES
1.00 WING GROUP	1.845915	1	.35
2.00 TAIL GROUP	1.845915	1	.35
3.00 BODY GROUP	1.845915	2	.36
3.10 TANKS-LOX	1.845915	1	.49
3.20 TANKS-LH2	1.845915	1	.49
4.10 IEP-TILES	4.5	7	.00026
4.20 IEP-TCS	4.5	1	.00026
4.30 IEP-PVD	4.5	1	.0043
5.00 LANDING GEAR	1.845915	1	.52
6.00 PROPULSION-MAIN	2.43	1	.46
7.00 PROPULSION-RCS	2.43	1	.46
8.00 PROPULSION-OMS	2.43	1	.46
9.30 POWER-FUEL CELL	4.5	1	.1559
10.00 ELECTRICAL	1.98833	1	.57
12.00 AERO SURF ACTUATORS	1.845915	1	.47
13.10 AVIONICS-GN&C	2.18	1	.49
13.20 AV-HEALTH MONITOR	2.18	1	.38
13.30 AVIONICS-COMM & TRACK	2.18	1	.52
13.50 AVIONICS-INSTRUMENTS	2.18	1	.55
13.60 AVIONICS-DATA PROC	2.18	1	.5
14.10 ENVIRONMENTAL CONTROL	1.98833	2	.41
3.30 TANKS-RP	2.157228	1	.49
6.10 PROPULSION-MPS	2.43	1	.46

Note - FRACTION INHERENT FAILURES - fraction of total maint. actions resulting from inherent failures; separates MTBM into a ground & mission MTBM

G. SUBSYSTEM REDUNDANCY & SCHEDULED MAINTENANCE

SUSBSYTEM	REDUNDANT SUBSYS	MIN NBR REQUIRED	SCHEDULED MAINT. HOURS	PCT OF UNSCH
1.00 WING GROUP	1	1	6.431775	52.922
2.00 TAIL GROUP	1	1	1.016515	52.922
3.00 BODY GROUP	1	1	24.08364	52.922
3.10 TANKS-LOX	1	1	4.194798	20.51
3.20 TANKS-LH2	1	1	4.3831	21.98
4.10 IEP-TILES	1	1	394.0145	42
4.20 IEP-TCS	1	1	34.57538	52.922
4.30 IEP-PVD	1	1	2.835435	52.922
5.00 LANDING GEAR	1	1	11.11162	52.922
6.00 PROPULSION-MAIN	7	6	23.61215	52.922
7.00 PROPULSION-RCS	1	1	1.9757	52.922
8.00 PROPULSION-OMS	1	1	.92827	52.922
9.30 POWER-FUEL CELL	1	1	24.5	52.913
10.00 ELECTRICAL	1	1	2.86712	52.922
12.00 AERO SURF ACT	1	1	4.276447	52.922
13.10 AVIONICS-GN&C	1	1	8.8431	52.922
13.20 AV-HEALTH MONITOR	1	1	.007548	52.918
13.30 AV-COMM & TRACK	1	1	.23204	52.922
13.50 AVIONICS-INSTR	1	1	.0294	52.922
13.60 AV-DATA PROC	1	1	.54726	52.922
14.10 ENVIRON CNTRL	1	1	39.3123	52.922
3.30 TANKS-RP	1	1	2.42757	52.922
6.10 PROPULSION-MPS	1	1	9.737	52.968

CURRENT SCHEDULED MAINTENANCE PERCENT (of unsch maint hrs) 50.8694

Parametric equation default Percent 37.83028

Periodic (phase) Maintenance Requirement

1 - NBR missions btwn inspections		1
2 - Length of inspection in hours		0
3 - Crew size for phase inspection		1

H. SHUTTLE (User Specified) UTILIZED VALUES

SUBSYSTEM	MTBM	MH/MA
4.10 IEP-TILES	1.29	22.05
4.20 IEP-TCS	24.95	29.7
4.30 IEP-PVD	384.45	37.53
9.30 POWER-FUEL CELL	113.1	64.8
3.30 TANKS-RP	22.2805	5.6
6.10 PROPULSION-MPS	11.63908	11.39

APPENDIX D
BASECASE OUTPUT REPORT

A. RELIABILITY REPORT - at mission nbr. 1

All MTBM's are for a single subsystem, e.g. one engine

WBS MTBM	TECH/GROWTH MTBM (all)	GRND PROC MTBM (External)	MISSION (inherent)
1.00 WING GROUP	29.74696	9.459019	296.8781
2.00 TAIL GROUP	169.2699	59.84983	1878.43
3.00 BODY GROUP	10.20035	2.554177	76.73882
3.10 TANKS-LOX	30.42789	17.31625	304.5893
3.20 TANKS-LH2	29.27236	16.57233	291.5039
4.10 IEP-TILES	4.207253	.2351032	15277.74
4.20 IEP-TCS	81.37284	4.547151	295488
4.30 IEP-PVD	1253.859	70.35051	275304.9
5.00 LAND GR MSN'S/FAIL	.7909822	.8568973	.7909822
6.00 PROPULSION-MAIN	20.15033	61.30392	1.007517
7.00 PROPULSION-RCS	23.74515	104.6659	8.723674
8.00 PROPULSION-OMS	26.98583	222.767	12.02942
9.30 POWER-FUEL CELL	256.107	16.57969	1552.996
10.00 ELECTRICAL	52.66218	25.22993	344.4992
12.00 AERO SURF ACTUATORS	11.70854	4.903376	93.44582
13.10 AVIONICS-GN&C	29.53225	13.95451	251.2666
13.20 AV-HEALTH MONITOR	37679.98	13447.3	379567.7
13.30 AVIONICS-COMM & TR	900.6169	565.0464	9023.358
13.50 AVIONICS-INSTR	1972.034	1400.047	19817.03
13.60 AVIONICS-DATA PROC	260.6892	148.9581	2576.974
AVIONICS ROLLUP	25.41861	12.35588	220.6624
14.10 ENVIRONMENTAL CTRL	8.744435	1.896258	47.20758
3.30 TANKS-RP	40.70857	23.93771	421.0594
6.10 PROPULSION-MPS	13.71469	41.72459	.6857346
VEHICLE	.4529217	.1370822	.2513259

WBS	CRITICAL FAILURE RATE-air only	CRITICAL MTBM	SUBSYS NON-REDUNDANT MSN REL
1.00 WING GROUP	1.942436E-04	1528380	.9999902
2.00 TAIL GROUP	1.942436E-04	9670485	.9999985
3.00 BODY GROUP	1.575159E-04	487181.4	.9999694
3.10 TANKS-LOX	.0001	3045893	.9999951
3.20 TANKS-LH2	.0001	2915039	.9999949
4.10 IEP-TILES	.00065	2.350421E+07	.9999993
4.20 IEP-TCS	.00065	4.545969E+08	1
4.30 IEP-PVD	.00065	4.23546E+08	1
5.00 LANDING GEAR	4.987509E-04	1585.926	.9993697
6.00 PROPULSION-MN	.00065	1550.026	.9981952
7.00 PROPULSION-RCS	.00065	13421.04	.999891
8.00 PROPULSION-OMS	.00065	18506.8	.9999589
9.30 POWER-FUEL CELL	.00065	2389225	.9999937
10.00 ELECTRICAL	.00031	1111288	.9999866
12.00 AERO SURF ACT	4.331814E-04	215719.8	.9999309
13.10 AVIONICS-GN&C	.0033	76141.38	.9998043
13.20 AV-HEALTH MON	.001	3.795677E+08	1
13.30 AV-COMM & TRACK	.0012925	6981322	.9999979
13.50 AVIONICS-INSTR	.0024	8257095	.9999982
13.60 AV-DATA PROC	.001	2576974	.9999942
AVIONICS ROLLU	.0017985 AVG	72524.22	.9997945
14.10 ENVIRON CNTRL	.0004408	107095.2	.9998608
3.30 TANKS-RP	.0001	4210595	.9999965
6.10 PROPULSION-MPS	.00065	1054.976	.9973494
VEHICLE		419.2915	.9942859

NOTE: reliabilities are based upon redundancy

WBS	LAUNCH TIME	END OF POWER FLT	ORBIT INSERTION
1.00 WING GROUP	1	.9999982	.9999976
2.00 TAIL GROUP	1	.9999997	.9999996
3.00 BODY GROUP	1	.9999943	.9999925
3.10 TANKS-LOX	1	.9999991	.9999988
3.20 TANKS-LH2	1	.999999	.9999987
4.10 IEP-TILES	1	.9999999	.9999998
4.20 IEP-TCS	1	1	1
4.30 IEP-PVD	1	1	1
5.00 LANDING GEAR	1	1	1
6.00 PROPULSION-MAIN	1	.999932	.999932
7.00 PROPULSION-RCS	1	.9999851	.9999776
8.00 PROPULSION-OMS	1	.9999892	.9999757
9.30 POWER-FUEL CELL	1	.9999988	.9999985
10.00 ELECTRICAL	1	.9999975	.9999967
12.00 AERO SURF ACTUATORS	1	.999987	.999983
13.10 AVIONICS-GN&C	1	.9999632	.999952
13.20 AV-HEALTH MONITOR	1	1	1
13.30 AVIONICS-COMM & TRACK	1	.9999996	.9999995
13.50 AVIONICS-INSTRUMENTS	1	.9999996	.9999996
13.60 AVIONICS-DATA PROC	1	.9999989	.9999986
AVIONICS ROLLUP	1	.9999614	.9999496
14.10 ENVIRONMENTAL CONTROL	1	.9999738	.9999658
3.30 TANKS-RP	1	.9999993	.9999991
6.10 PROPULSION-MPS	1	.9973494	.9973494
VEHICLE	1	.9971642	.9971152

WBS	REENTRY	MISSION COMPLETION
1.00 WING GROUP	.9999909	.9999902
2.00 TAIL GROUP	.9999986	.9999985
3.00 BODY GROUP	.9999714	.9999694
3.10 TANKS-LOX	.9999954	.9999951
3.20 TANKS-LH2	.9999952	.9999949
4.10 IEP-TILES	.9999994	.9999993
4.20 IEP-TCS	1	1
4.30 IEP-PVD	1	1
5.00 LANDING GEAR	1	.9993697
6.00 PROPULSION-MAIN	.999932	.999932
7.00 PROPULSION-RCS	.9998984	.999891
8.00 PROPULSION-OMS	.9999644	.9999589
9.30 POWER-FUEL CELL	.9999942	.9999937
10.00 ELECTRICAL	.9999875	.9999866
12.00 AERO SURF ACTUATORS	.9999355	.9999309
13.10 AVIONICS-GN&C	.9998174	.9998043
13.20 AV-HEALTH MONITOR	1	1
13.30 AVIONICS-COMM & TRACK	.999998	.9999979
13.50 AVIONICS-INSTRUMENTS	.9999983	.9999982
13.60 AVIONICS-DATA PROC	.9999946	.9999942
AVIONICS ROLLUP	.9998083	.9997945
14.10 ENVIRONMENTAL CONTROL	.9998701	.9998608
3.30 TANKS-RP	.9999967	.9999965
6.10 PROPULSION-MPS	.9973494	.9973494
VEHICLE	.9966893	.9960157

B. MAINTAINABILTY REPORT - at mission nbr. 1

UNSCHEDULED-on/off vehicle maintenance

WBS	MAINT ACTIONS/MSN	AVG MANHR/MA	AVG MANHRS/MSN
1.00 WING GROUP	1.626449	7.472283	12.15329
2.00 TAIL GROUP	.2570536	7.472283	1.920777
3.00 BODY GROUP	6.117431	7.439025	45.50772
3.10 TANKS-LOX	1.132338	18.06202	20.45231
3.20 TANKS-LH2	1.183167	16.853	19.93992
4.10 IEP-TILES	42.54557	22.05	938.1299
4.20 IEP-TCS	2.199751	29.7	65.33261
4.30 IEP-PVD	.1427592	37.53	5.357754
5.00 LANDING GEAR	2.431252	8.635959	20.99619
6.00 PROPULSION-MAIN	2.114541	21.1	44.61681
7.00 PROPULSION-RCS	.1769298	21.1	3.73322
8.00 PROPULSION-OMS	8.312954E-02	21.1	1.754033
9.30 POWER-FUEL CELL	.7145452	64.8	46.30253
10.00 ELECTRICAL	.9217549	5.877515	5.417628
12.00 AERO SURF ACT	3.847946	2.1	8.080686
13.10 AVIONICS-GN&C	1.405126	11.89189	16.7096
13.20 AV-HEALTH MON	1.199426E-03	11.89189	1.426343E-02
13.30 AV-COMM & TRCK	3.687012E-02	11.89189	.4384554
13.50 AV-INSTR	1.587248E-02	3.5	5.555369E-02
13.60 AV-DATA PROC	.134266	7.701766	1.034085
AVIONICS ROLLUP	1.593334	9.375486 (AVG)	18.25196
14.10 ENVIRON CNTRL	8.938209	8.310772	74.28341
3.30 TANKS-RP	.8191195	5.6	4.587069
6.10 PROPULSION-MPS	.4438275	41.41819	18.38253
TOTALS -unsch on/off	77.28912	17.53417 WT-AVG	1355.2

MAINTAINABILTY REPORT - at mission nbr. 1

note: MTTR is for a single maintenance action

WBS	UNSCHEDULED ON-VEH MH	UNSCHEDULED OFF-VEH MH	ON-VEH MTTR (hrs)
1.00 WING GROUP	11.13849	1.0148	3.710001
2.00 TAIL GROUP	1.760392	.1603849	3.710001
3.00 BODY GROUP	41.60544	3.902287	3.684422
3.10 TANKS-LOX	20.45231	0	9.78486
3.20 TANKS-LH2	19.93992	0	9.129891
4.10 IEP-TILES	938.1299	0	4.9
4.20 IEP-TCS	65.33261	0	6.6
4.30 IEP-PVD	5.357754	0	8.34
5.00 LANDING GEAR	15.20139	5.7948	3.387207
6.00 PROP-MAIN	12.26962	32.34719	2.38786
7.00 PROP-RCS	1.026635	2.706584	2.38786
8.00 PROP-OMS	.4823591	1.271674	2.38786
9.30 PWR-FUEL CELL	46.30253	0	14.4
10.00 ELECTRICAL	4.275494	1.142135	2.332826
12.00 ACTUATORS	5.737287	2.343399	.8077295
13.10 AV-GN&C	7.820095	8.889509	2.552938
13.20 AV-HLTH MON	6.675288E-03	7.588148E-03	2.552938
13.30 AV-COMM & TRK	.2051971	.2332583	2.552938
13.50 AV-INSTR	3.111007E-02	2.444362E-02	.8990825
13.60 AV-DATA PROC	.4839519	.5501333	1.653407
AVIONICS ROLLUP	8.547029	9.704933	2.443911
14.10 ENV CONTROL	67.3602	6.923214	3.79022
3.30 TANKS-RP	4.587069	0	2.595924
6.10 PROP-MPS	5.055195	13.32733	4.687243
UNSCHEDULED	1274.562	80.63873	3.663318 (WAVG)
SCHEDULED	648.3619		
PHASE INSP	0		
TOTAL	1922.924		

MAINTAINABILTY REPORT - at mission nbr. 1

WBS	SCHED MH/MSN	UNSCHED MH/MSN	TOTAL MH/MSN
1.00 WING GROUP	6.431775	12.15329	18.58506
2.00 TAIL GROUP	1.016515	1.920777	2.937292
3.00 BODY GROUP	24.08364	45.50772	69.59136
3.10 TANKS-LOX	4.194798	20.45231	24.6471
3.20 TANKS-LH2	4.3831	19.93992	24.32302
4.10 IEP-TILES	394.0145	938.1299	1332.144
4.20 IEP-TCS	34.57538	65.33261	99.90799
4.30 IEP-PVD	2.835435	5.357754	8.19319
5.00 LANDING GEAR	11.11162	20.99619	32.10781
6.00 PROPULSION-MAIN	23.61215	44.61681	68.22896
7.00 PROPULSION-RCS	1.9757	3.73322	5.70892
8.00 PROPULSION-OMS	.92827	1.754033	2.682303
9.30 POWER-FUEL CELL	24.5	46.30253	70.80254
10.00 ELECTRICAL	2.86712	5.417628	8.284748
12.00 ACTUATORS	4.276447	8.080686	12.35713
13.10 AVIONICS-GN&C	8.8431	16.7096	25.5527
13.20 AV-HEALTH MON	.007548	1.426344E-02	2.1813E-02
13.30 AV-COMM & TRACK	.23204	.4384554	.6704954
13.50 AV-INSTRUMENTS	.0294	5.555369E-02	.0849537
13.60 AV-DATA PROC	.54726	1.034085	1.581345
AVIONICS ROLLUP	9.659348	18.25196	27.91131
14.10 ENVIRON CONTROL	39.3123	74.28342	113.5957
3.30 TANKS-RP	2.42757	4.587069	7.014639
6.10 PROPULSION-MPS	9.737	18.38253	28.11953
TOTAL	648.3619	1355.2	2003.562

MAINTAINABILTY REPORT - at mission nbr. 1

Note: Ground processing MA's consist of induced and no defect MA's.
Mission MA's are inherent equipment failures

WBS	GRND PROC MA	MSN MA	TOTAL MA
1.00 WING GROUP	1.057192	.5692573	1.626449
2.00 TAIL GROUP	.1670849	8.996876E-02	.2570536
3.00 BODY GROUP	3.915156	2.202275	6.117431
3.10 TANKS-LOX	.5774922	.5548456	1.132338
3.20 TANKS-LH2	.6034154	.5797521	1.183167
4.10 IEP-TILES	42.53451	1.106185E-02	42.54557
4.20 IEP-TCS	2.199179	5.719353E-04	2.199751
4.30 IEP-PVD	.1421454	6.138649E-04	.1427592
5.00 LANDING GEAR	1.167001	1.264251	2.431252
6.00 PROPULSION-MAIN	1.141852	.9726887	2.114541
7.00 PROPULSION-RCS	9.554211E-02	8.138773E-02	.1769298
8.00 PROPULSION-OMS	4.488995E-02	3.823959E-02	8.3129E-02
9.30 POWER-FUEL CELL	.6031476	.1113976	.7145452
10.00 ELECTRICAL	.3963546	.5254003	.9217549
12.00 ACTUATORS	2.039411	1.808535	3.847946
13.10 AVIONICS-GN&C	.7166144	.6885118	1.405126
13.20 AV-HEALTH MON	7.436438E-04	4.55781E-04	1.199E-03
13.30 AV-COMM & TRACK	1.769766E-02	1.91724E-02	3.687E-02
13.50 AVIONICS-INSTR	7.142617E-03	8.7298E-03	1.587E-02
13.60 AV-DATA PROC	6.713299E-02	6.713299E-02	.134266
AVIONICS ROLLUP	.8093312	.784003	1.593334
14.10 ENVIRONCONTROL	5.273543	3.664665	8.938209
3.30 TANKS-RP	.4177509	.4013685	.8191195
6.10 PROPULSION-MPS	.2396668	.2041606	.4438275
TOTAL	63.42467	13.86444	77.28912

C. MANPOWER REPORT - at mission nbr. 1

manpwr is computed from manhrs/mo divided by avail direct hrs per mo per person
available hrs per mo is 144 and the percent indirect is 15

WBS	MAINT MANHRS/MSN	MANHRS/MO	MANPWR
1.00 WING GROUP	18.58506	46.46266	1
2.00 TAIL GROUP	2.937292	7.343231	1
3.00 BODY GROUP	69.59136	173.9784	2
3.10 TANKS-LOX	24.6471	61.61776	1
3.20 TANKS-LH2	24.32302	60.80756	1
4.10 IEP-TILES	1332.144	3330.361	28
4.20 IEP-TCS	99.90799	249.77	3
4.30 IEP-PVD	8.19319	20.48298	1
5.00 LANDING GEAR	32.10781	80.26953	1
6.00 PROPULSION-MAIN	68.22896	170.5724	2
7.00 PROPULSION-RCS	5.70892	14.2723	1
8.00 PROPULSION-OMS	2.682303	6.705759	1
9.30 POWER-FUEL CELL	70.80254	177.0063	2
10.00 ELECTRICAL	8.284748	20.71187	1
12.00 AERO SURF ACTUATORS	12.35713	30.89283	1
13.10 AVIONICS-GN&C	25.5527	63.88176	1
13.20 AV-HEALTH MONITOR	2.181143E-02	5.452859E-02	0
13.30 AVIONICS-COMM & TRACK	.6704954	1.676239	1
13.50 AVIONICS-INSTRUMENTS	.0849537	.2123842	1
13.60 AVIONICS-DATA PROC	1.581345	3.953363	1
AVIONICS ROLLUP	27.91131	69.77827	4
14.10 ENVIRONMENTAL CONTROL	113.5957	283.9893	3
3.30 TANKS-RP	7.014639	17.5366	1
6.10 PROPULSION-MPS	28.11953	70.29883	1
TOTAL	1957.143	4892.857	56
Pad Svc			20
Phase inspt	0	0	0

MANPOWER REPORT - at mission nbr. 1

Rqd crews is computed from manpwr divided by avg crew. Asgn manpwr is based on a posn manning fac of 1.372549. Max mpwr is MAX {manpwr, asgn manpwr}.

WBS	AVG CREW SIZE	RQD CREWS	CUR ASGD CREWS	ASGN POSNS	ASGN MNPWR	MAX MPWR
1.00 WING GROUP	1.845915	1	1	2	3	3
2.00 TAIL GROUP	1.845915	1	1	2	3	3
3.00 BODY GROUP	1.845915	2	2	4	6	6
3.10 TANKS-LOX	1.845915	1	1	2	3	3
3.20 TANKS-LH2	1.845915	1	1	2	3	3
4.10 IEP-TILES	4.5	7	7	32	44	44
4.20 IEP-TCS	4.5	1	1	5	7	7
4.30 IEP-PVD	4.5	1	1	5	7	7
5.00 LANDING GEAR	1.845915	1	1	2	3	3
6.00 PROP-MAIN	2.43	1	1	3	5	5
7.00 PROP-RCS	2.43	1	1	3	5	5
8.00 PROP-OMS	2.43	1	1	3	5	5
9.30 PWR-FUEL CELL	4.5	1	1	5	7	7
10.00 ELECTRICAL	1.98833	1	1	2	3	3
12.00 ACTUATORS	1.845915	1	1	2	3	3
13.10 AV-GN&C	2.18	1	1	3	5	5
13.20 AV-HEALTH MON	2.18	1	1	3	5	5
13.30 AV-COMM&TRACK	2.18	1	1	3	5	5
13.50 AV-INSTR	2.18	1	1	3	5	5
13.60 AV-DATA PROC	2.18	1	1	3	5	5
14.10 ENVIRON CONTR	1.98833	2	2	4	6	6
3.30 TANKS-RP	2.157228	1	1	3	5	5
6.10 PROP-MPS	2.43	1	1	3	5	5
TOTAL				99	148	148
Pad Svc					20	20
Phase Inspect				1	0	0
TOTAL RQMT						168

D. SUBSYSTEM SPARES REPORT - at mission nbr. 1
NOTE: failures are assumed to be Poisson

WBS	REMOVAL RATE/MA	MEAN NUMBER IN REPAIR	SPARES RQMT	EFFECTIVE FILL RATE
1.00 WING GROUP	.1923022	.3127698	4	.9636297
2.00 TAIL GROUP	.1923022	4.943197E-02	1	.9664662
3.00 BODY GROUP	.2229133	1.363657	13	.9701723
3.10 TANKS-LOX	.2758	.3122987	4	.9638251
3.20 TANKS-LH2	.2758	.3263176	4	.9577278
4.10 IEP-TILES	.001	4.254558E-02	1	.9745088
4.20 IEP-TCS	.481	1.05808	10	.9536552
4.30 IEP-PVD	.391	5.581887E-02	1	.9582492
5.00 LANDING GEAR	.22	.5348755	6	.9624395
6.00 PROPULSION-MAIN	.555609	1.174858	11	.9567808
7.00 PROPULSION-RCS	.5975044	.1057163	2	.9760638
8.00 PROPULSION-OMS	.5968578	4.961651E-02	1	.9662386
9.30 POWER-FUEL CELL	.261	.1864963	3	.9762061
10.00 ELECTRICAL	.5007281	.4615485	6	.9809969
12.00 ACTUATORS	.38593	1.485038	14	.971503
13.10 AVIONICS-GN&C	.4	.5620505	6	.9533011
13.20 AV-HEALTH MON	.4147191	4.974247E-04	0	.9971422
13.30 AV-COMM & TRACK	.4	1.474805E-02	1	.9965974
13.50 AV-INSTRUMENTS	.51	8.094966E-03	0	.9544941
13.60 AV-DATA PROC	.4147191	5.568267E-02	1	.9584317
AVIONICS ROLLUP	4278876 (AVG)	.6410735		8.9719933
14.10 ENVIRONMENTAL CON	.5151376	4.604407	35	.95
3.30 TANKS-RP	.164	.1343356	2	.9563957
6.10 PROPULSION-MPS	.555609	.2465945	4	.9849931
TOTALS	.3706058 (AVG)	13.14548	130	.3597566

E. VEHICLE TURN TIME REPORT - at mission nbr. 1

WBS	ON-VEHICLE MTTR (HRS)	TOT MAIN ACT	NBR CREWS ASSIGNED	AVG ON-VEH MAINT. TIME PER MSN-hrs
1.00 WING GROUP	3.710001	1.626449	1	9.448772
2.00 TAIL GROUP	3.710001	.2570536	1	1.493339
3.00 BODY GROUP	3.684422	6.117431	2	17.66262
3.10 TANKS-LOX	9.78486	1.132338	1	13.30679
3.20 TANKS-LH2	9.129891	1.183167	1	13.12919
4.10 IEP-TILES	4.9	42.54557	7	42.04013
4.20 IEP-TCS	6.6	2.199751	1	22.04811
4.30 IEP-PVD	8.34	.1427592	1	1.808107
5.00 LANDING GEAR	3.387207	2.431252	1	14.13433
6.00 PROPULSION-MAIN	2.38786	2.114541	1	14.57182
7.00 PROPULSION-RCS	2.38786	.1769298	1	1.219268
8.00 PROPULSION-OMS	2.38786	8.312954E-02	1	.5728657
9.30 POWER-FUEL CELL	14.4	.7145452	1	15.62501
10.00 ELECTRICAL	2.332826	.9217549	1	3.563428
12.00 ACTUATORS	.8077295	3.847946	1	5.378474
13.10 AVIONICS-GN&C	2.552938	1.405126	1	7.562538
13.20 AV-HEALTH MON	2.552938	1.199426E-03	1	6.4552E-03
13.30 AV-COMM & TRACK	2.552938	3.687012E-02	1	.1984387
13.50 AV-INSTRUMENTS	.8990825	1.587248E-02	1	2.74872E-02
13.60 AV-DATA PROC	1.653407	.134266	1	.4680122
AVIONICS ROLLUP WAVG	2.443911	1.593334	5	8.262931
14.10 ENVIRON CON	3.79022	8.938209	2	26.62693
3.30 TANKS-RP	2.595924	.8191195	1	3.229185
6.10 PROPULSION-MPS	4.687243	.4438275	1	6.007183

WAVG CREW SIZE 2.223439 WAVG TASK TIME 3.663318 220.1285 (TOTAL)

Note: Avg subsystem repair time includes on-veh scheduled maintenance.

VEHICLE TURN TIME REPORT - at mission nbr. 1

INTEGRATION TIME	0 DAYS
LAUNCH PAD TIME	.5 DAYS
PHASE INSPECTION TIME (per msn)	0 hrs
MISSION TIME -INC GRND PWR TIME	168 HRS

CATEGORY	MIN TURN TIME (parallel)	WT-AVG 10 % OF MAX	MAX TURN TIME (sequential)
SCHED/UNSCHED MAINT TIME	42.04013	59.84896	220.1285 HRS
VEH GRN PROC TIME	54.04013 HRS	71.84897	232.1285 HRS
TOT VEH TURNAROUND TIME	222.0401 HRS	239.849	400.1285 HRS
1 -SHIFT/DAY MAINTENANCE			
VEH GRND PROCESSING DAYS	5.755016	7.981121	28.01606
TOT VEH TURNAROUND DAYS	12.75502	14.98112	35.01606
AVG MISSIONS/YR/VEHICLE	24.97912	20.60669	7.889612
COMPUTED FLEET SIZE	2	2	4
2 -SHIFT/DAY MAINTENANCE			
VEH GRND PROCESSING DAYS	3.127508	4.240561	14.25803
TOT VEH TURNAROUND DAYS	10.12751	11.24056	21.25803
AVG MISSIONS/YR/VEHICLE	33.16614	29.14298	13.73439
COMPUTED FLEET SIZE	1	2	3
3 -SHIFT/DAY MAINTENANCE			
VEH GRND PROCESSING DAYS	2.251672	2.993707	9.672022
TOT VEH TURNAROUND DAYS	9.251672	9.993707	16.67202
AVG MISSIONS/YR/VEHICLE	37.16432	33.72257	18.17174
COMPUTED FLEET SIZE	1	1	2

NOTE: assumes 8 hr shifts, and 21 work days a month

F. SYSTEM PERFORMANCE SUMMARY - at mission nbr. 1

RELIABILITY REPORT

CATEGORY	LAUNCH TIME	END OF POWER FLT	ORBIT INSERTION
VEHICLE	1	.9971642	.9971152

	REENTRY	MISSION COMPLETION
VEHICLE	.9966893	.9960157

MAINTAINABILITY REPORT

UNSCHED CATEGORY	MAINT ACTIONS/MSN	WT-AVG MANHR/MA	AVG MANHRS/MSN
VEHICLE	77.28912	17.53417	1355.2

	ON-VEH MH	OFF-VEH MH	TOTAL MH
VEHICLE			
UNSCHED	1274.562	80.63873	1355.2
SCHEDULED	635.3947	12.96724	648.3619
PERIODIC INSP	0	0	0
TOTAL	1909.956	93.60597	2003.562

MANPOWER/SPARES REPORT

Mission rate is 30 missions per year. Position manning factor is 1.372549

TOTAL SPARES REQUIRED = 130

CATEGORY	MANPOWER RQMTS MANHR DRIVEN AGGREGATE	MANHR DRIVEN BY SUBSYS	MISSION RQMTS ASGN POS BY SUBSYS	ASGN MANPWR BY SUBSYS	MAX MANPWR
VEHICLE					
VEH MANPWR	40	56	99	148	148
PAD	20	20		20	20
PHASE INSP	0	0	1	0	0
TOTAL	60	76	100	168	168
EXT TANK					
LRB					

Initial R&M Values

All MTBM's are for a single subsystem.
Adj MTBM includes technology and reliability growth. MTTR=MHMA/crew size

WBS	unadj - MTBM	adj - MTBM	MTTR
1.00 WING GROUP	5.68421	29.74696	4.04801
2.00 TAIL GROUP	32.34501	169.2699	4.04801
3.00 BODY GROUP	1.949139	10.20035	4.029994
3.10 TANKS-LOX	16.35748	30.42789	9.78486
3.20 TANKS-LH2	15.73629	29.27236	9.129891
4.10 IEP-TILES	1.29	4.207253	4.9
4.20 IEP-TCS	24.95	81.37284	6.6
4.30 IEP-PVD	384.45	1253.859	8.34
5.00 LANDING GR MSN'S/FAI	.7909822	.8568973	4.678416
6.00 PROPULSION-MAIN	16.0143	20.15033	8.683127
7.00 PROPULSION-RCS	18.87125	23.74515	8.683127
8.00 PROPULSION-OMS	21.44675	26.98583	8.683127
9.30 POWER-FUEL CELL	113.1	256.107	14.4
10.00 ELECTRICAL	52.66218	52.66218	2.956006
12.00 AERO SURF ACTUATORS	3.728726	11.70854	1.137647
13.10 AVIONICS-GN&C	3.3	29.53225	5.454995
13.20 AV-HEALTH MONITOR	4210.446	37679.98	5.454995
13.30 AVIONICS-COMM & TRACK	100.637	900.6169	5.454995
13.50 AVIONICS-INSTRUMENTS	220.3595	1972.034	1.605505
13.60 AVIONICS-DATA PROC	29.13	260.6892	3.53292
AVIONICS ROLLUP	2.840333	25.41861	5.217964
14.10 ENVIRONMENTAL CONTROL	7.68	8.744435	4.179775
3.30 TANKS-RP	22.2805	40.70857	2.595924
6.10 PROPULSION-MPS	11.63908	13.71469	17.04452
VEHICLE	.1910728	.4529217	5.287127

Aggregated System Report - System Aggregation - page 1

Structural
- 1.00 WING GROUP
- 2.00 TAIL GROUP
- 3.00 BODY GROUP

Fuel/Oxid Tanks
- 3.10 TANKS-LOX
- 3.20 TANKS-LH2

Auxiliary Systems
- 3.30 TANKS-RP
- 16.40 REC&AUX-CROSS FEED
- 16.50 REC & AUX DOCK SYS

Thermal/Tiles
- 4.10 IEP-TILES
- 4.20 IEP-TCS
- 4.30 IEP-PVD

PROPULSION
- 6.00 PROPULSION-MAIN
- 7.00 PROPULSION-RCS
- 8.00 PROPULSION-OMS
- 6.10 PROPULSION - MPS

Power/Electrical
- 9.10 POWER-APU
- 9.20 POWER-BATTERY
- 9.30 POWER-FUEL CELL
- 10.00 ELECTRICAL

Mechanical Sys
- 11.00 HYDRAULICS/PNEUMATICS
- 12.00 AERO SURF ACTUATORS
- 5.00 LANDING GEAR

Avionics
- 13.10 AVIONICS-GN&C
- 13.20 AV-HEALTH MONITOR
- 13.30 AVIONICS-COMM & TRACK
- 13.40 AV-DISPLAYS & CONTR
- 13.50 AVIONICS-INSTRUMENTS
- 13.60 AVIONICS-DATA PROC

ECS/Life Support
- 14.10 ENVIRONMENTAL CONTROL
- 14.20 ECS-LIFE SUPPORT
- 15.00 PERSONNEL PROVISIONS
- 16.10 REC & AUX-PARACHUTES
- 16.20 REC & AUX-ESCAPE SYS

Aggregated System	Nbr of Maint Actions	On-Veh MTTR per MA (hrs)	On-Veh Sched maint time(hrs)	Ave Crew Size
Structural	8.000934	3.690444	16.74037	1.845915
Fuel/Oxid	2.315505	9.450187	4.554023	1.845915
Thermal/Tiles	44.88808	4.994249	93.95484	4.5
Propulsion	2.3746	2.38786	10.69374	2.43
Power/Elec	1.6363	7.602362	6.74869	3.085135
Mech Sys	6.279198	1.806481	8.169556	1.845915
Avionics	1.593334	2.460661	4.342276	2.18
ECS/Life SPT	8.938209	3.79022	19.37609	1.98833
Auxiliary Sys	1.262947	3.330859	5.029669	2.253086
Total	77.28911	39.51332	169.6092	21.9743
Average	8.587679	4.390369	18.84547	2.441588

note: MTTR's assume the Avg Crew Size and are based upon a weighted avg (wts-fraction of total failures) of each subsystem.

Aggregated system	Removal Rate	Off-Veh MTTR	Off-Veh Sched maint time(hrs)	Nbr Crew Assigned
Structural	.2157071	.3437915	.3416401	4
Fuel/Oxid Tanks	.2758	0	9.293925E-02	2
Thermal/Tiles	2.576284E-02	0	1.917446	9
Propulsion	.5601746	6.295267	.2182397	3
Power/Electrical	.3960428	.3510475	.1377284	2
Mechanical Sys	.3216833	.7021218	.1667256	2
Avionics	.4023472	2.794017	8.861786E-02	5
ECS/Life Support	.5151376	.389555	.3954304	2
Auxiliary Systems	.30162	4.34262	.1026463	2
Total		15.21842	3.461413	31
Average	.3349195	1.690936	.3846015	3.444444

note: MTTR's assume the Avg Crew Size and are based upon a weighted avg (wts- fraction of total failures) of each subsystem.

APPENDIX E
INPUT/OUTPUT VALUES
BASECASE COSTING MODEL

INPUT DATA

A. SYSTEM PARAMETERS

NBR	PARAMETER	VALUE
1	NBR OF VEHICLES	2
2	FLIGHTS/YR - FLEET	30
3	HOURS/MISSION	168
4	SYS LIFE IN YRS	11
5	BASE YEAR $	1995
6	CONSTANT $'s 0-NO/1-YES	1
7	INITIAL BEDDOWN	2007
8	NBR TEST VEHICLES	1
9	FUTURE INFLATION RATE	3.00 %
10	reserved	0
11	TFF (mo since Jan50)	600
12	LOG COST MODEL-0 HYPERVEL-1	0

B. COST FACTORS & RATES TABLE

NBR	CATEGORY	VALUE
1	Avg Cost of Prod Engines $M	$ 4.00000
2	Base Lvl Support Staff salary-$/hr	$ 15.00000
3	AVG Cost of Prod stages - eng/SRM-$M	$ 100.00000
4	Average LRU Cost-$	$ 129930.00000
5	ORG Technician salary - $/hr	$ 22.37000
7	Depot Technician Salary - $/hr	$ 25.94000
8	Logistics Salary - $/hr	$ 20.44000
9	Basic CBT cost-$/hr	$ 19598.00000
10	Depot Transporter Cost-$/lb-mi	$ 0.00020
11	DSE Costs-$K	$ 28681.00000
12	ECLSS Cost-$	$ 8313.00000
13	Page Change Cost	$ 249.00000
14	Rec Transporter Cost $/lb-mi	$ 0.00071
15	Transporter Cost $/lb-mi	$ 0.00071
16	Vehicle GSE-$K	$ 506862.00000
18	MPS Fuel Cost - $/lb	$ 2.80000
19	MPS Oxidizer Cost - $/lb	$ 0.02800
20	OMS Fuel Cost - $/lb	$ 0.17000
21	OMS Oxidizer Cost - $/lb	$ 0.00150
22	RCS Fuel Cost - $/lb	$ 0.17000
23	RCS Oxidizer Cost - $/lb	$ 0.00150
24	SE For Tot Refurb-$M	$ 3.00000
25	SE For Refurb Eng-$M	$ 2.00000
27	Tech Manual Page Costs	$ 920.00000
29	ATE Costs	$ 6989458.00000

C. DESIGN/PERFORMANCE VARIABLES

NBR	VARIABLE	VALUE
1	DRY WGT (LBS)	174160
2	VEH LENGTH+WING (ft)	279
3	CREW SIZE	0
4	NBR PASSENGERS	0
5	NBR MAIN ENGINES	7
6	FUSELAGE AREA	15564
7	FUSELAGE VOLUME	105712
8	TOT WETTED AREA	20631
9	NBR WHEELS	10
10	NBR ACTUATORS	7
11	NBR CONTRL SURFACES	7
12	MAX KVA	240
13	NBR HYDR SUBSYS	1
15	TOT NBR AVIONICS SUBSYS	5
16	NBR DIFF AVIONICS SUBSYS	5
17	BTU/HR/person	52
18	TAKEOFF GVW-LBS	1960531
19	SINK SPEED FT/SEC	9
32	LANDING MASS*VEL^2-lbxknots	433
33	LANDING WEIGHT	342271
34	NUMBER OF BRAKES/VEH	13
35	CARGO VOLUME [FT^3]	0
36	CARGO WEIGHT (PAYLOAD)	168111
38	NUMBER OF ANTENNAS	2
39	CARGO FLOOR AREA [FT^2]	1266
40	NUMBER OF GENERATORS	10
41	NUMBER OF HYD. PUMPS	8
42	NUMBER OF HYD. SUPPLY SYS.	3
44	NUMBER OF PRIMARY COMPARTMENTS	4
45	NBR OF SEATS INC BUNKS	0
46	AVIONICS BLACK BOX WGT -LBS	658
47	AVIONICS INSTALL WGT -LBS	658
48	MAXMACH NBR	7
49	LRU REMOVALS/FLIGHT	0
50	VEH TURNAROUND TIME-DAYS?	15
51	TOT NBR SUBSYSTEMS	39
52	MAINT SIGNF ITEM-LRUs	11
53	NBR LRU'S	500

D. MISCELLANEOUS FACTORS

NBR	CATEGORY	VALUE
1	Avionics fraction of LRUs	0.05
2	Commonality Factor	1.00
3	Percent Commercial Off-Shelf	0.30
4	Condemnation Rate (fraction)	0.03
5	Depot Coverage Factor	0.56
6	Depot Distance - mi	30.00
7	Duration Depot Trnging	200.00
8	Manual pages count per LRU	200.00
9	Kunique - % unique LRUs	0.09
10	Depot page change rate	0.05
11	Personnel turnover rate	0.06
12	Org page change rate	0.10
13	Depot Manhrs / repair	10.00
14	Initial CALS factor	0.70
15	Initial CBT Factor	0.50
16	Initial ILS Mgmt	0.08
17	Duration Orgn trng Course - hrs	40.00
18	Initial Warehouse manhrs	2.40
19	MPS Fuel Weight - lbs	227641.00
20	MPS Oxidizer Wt - lbs	1361936.00
21	OMS Fuel Weight - lbs	9010.00
22	OMS Oxidizer Wt - lbs	14866.00
23	RCS Fuel Weight - lbs	2954.00
24	RCS Oxidizer Wt - lbs	1853.00
25	Piece Parts per SRU	10.00
26	Packaging Wgt Tax	1.94
27	Quantity of stages flown	1.00
28	Recovery Distance - mi	2200.00
29	Recurring GSE cost factor	0.10
30	Recurring Inventory Factor	0.20
31	Recurring ILS mgmt	0.13
32	Recurring training factor	0.10
33	Recurring CALS Factor	0.30
34	Nbr SRU's per LRU	8.00
35	Nbr of ORG Technicians	182.00
36	TPS factor	320000.00
37	NBR Spare LRU'S	141.00
38	Frac LRUs repaired at Depot	0.61
39	Distance-Trans -MI	2100.00

OUTPUT - Cost Element Structure

WBS COST SUMMARY OVER A 11 YR SYSTEM LIFE

Life cycle costs are in constant 1995 dollars.

WBS	Cost [M year 1995 $]	LCC cost
2.1 Concept Devl (R&D)	0.000	0.000
2.1.1 Tech Prog	0.000	0.000
2.1.2 Phase A/B Cont	0.000	0.000
2.2 Acquisition (Invst)	0.000	0.000
2.2.1 Design & Devl	3236.716	3236.716
2.2.2 Production	2169.091	2169.091
2.2.3 Integration	0.000	0.000
2.2.4 Test & Eval	6709.877	6709.877
2.2.5 Prog Mgmt & Spt	0.000	0.000
2.2.6 Prog Sys Eng	0.000	0.000
2.3 Program Oper & Spt	2748.261	28010.656
2.3.1 Operations	21.618	237.797
2.3.1.1 Refurbishment	8.879	97.664
2.3.1.2 Organ. Maint.	12.739	140.133
2.3.1.3 Processing Ops	0.000	0.000
2.3.1.4 Integration Ops	0.000	0.000
2.3.1.5 Payload Ops	0.000	0.000
2.3.1.6 Transfer	0.000	0.000
2.3.1.7 Launch Operations	0.000	0.000
2.3.1.8 Mission Ops	0.000	0.000
2.3.1.9 Land/Rocv/Recv Ops	0.000	0.000
2.3.1.10 Non-nominal Ops	0.000	0.000
2.3.2 Logistics Spt	208.129	876.784
2.3.2.1 Depot Maint.	0.021	0.231
2.3.2.2 Modifications	9.748	107.227
2.3.3.3 Spares	14.091	14.559
2.3.3.4 Expendables	0.071	0.782
2.3.3.5 Consumables	24.488	247.109
2.3.3.6 Inv Mgmt & Warehse	0.606	0.610
2.3.3.7 Training	0.907	1.016
2.3.3.8 Documentation	61.999	115.847
2.3.3.9 Transportation	18.322	190.583
2.3.3.10 Support Equip	60.848	116.164
2.3.3.11 ILS Management	17.027	82.656

2.3.3 System Support	92.888	214.189
2.3.3.1 Support	9.880	108.684
2.3.3.2 Facility O&M	81.428	88.129
2.3.3.3 Communications	0.316	3.475
2.3.3.4 Base Ops	1.264	13.901
2.3.4 Program Support	879.985	9679.836
2.3.5 R&D	1545.641	17002.049
2.4 Prog Phaseout	0.000	0.000
TOTAL	2748.261	28010.656

APPENDIX F
Operations and Support Cost Model
Source Listing of Modified Modules

```
SUB RAMI
'MODULE TO INPUT DATA FROM RAM MODEL
     CLS : COLOR 11
     PRINT : PRINT TAB(10); "INPUT FILES from RAM model": PRINT
     FILES "*.CST"
     PRINT : COLOR 12
     PRINT TAB(10); "INPUT DATA WILL BE READ FROM "; VNAM$; ".CST"
     COLOR 10
     LOCATE 14, 10: INPUT "ENTER RETURN TO PROCEED ELSE ENTER A POSITIVE NBR ",
     IF NUM > 0 THEN GOTO BT5
     VN$ = VNAM$
     NSP = 0: NTC = 0
     OPEN VN$ + ".CST" FOR INPUT AS #1
     INPUT #1, VN$
     FOR I = 1 TO 34
        INPUT #1, W(I), S(I), MP(I), OPH(I), CA(I)
        NSP = NSP + S(I)
        NTC = NTC + MP(I)
     NEXT I
     INPUT #1, SMP, VX(50), XP(3), TNR ' SCH MNPW,VEH TAT,HRS/MSN,REMOVALS/FLIGH
     FOR I = 1 TO 13: INPUT #1, V(I): NEXT I
     FOR I = 1 TO 25: INPUT #1, X(I): NEXT I
     FOR I = 0 TO 5: INPUT #1, X: NEXT I
     INPUT #1, AREM, TMA
     INPUT #1, TME, TMF 'ET AND LBR MANPOWER
     FOR I = 1 TO 9: INPUT #1, CZ(I), SC(I): NEXT I   'nbr crews asgn & avg crew
     PRINT : PRINT : PRINT TAB(10); "DATA INPUT FROM ";
     COLOR 10: PRINT VNAM$; ".CST"
     CLOSE #1
     VX(49) = TNR / XP(2)      'converts to removals/flgt
     CZ(10) = SMP
     MCF(37) = NSP
     MCF(35) = INT(NTC + SMP + .5)
     XP(2) = X(15)                 'FLIGHTS/YR
     AVWT = 0
     FOR I = 19 TO 24: AVWT = AVWT + W(I): NEXT I
     FOR I = 1 TO 5: VX(I) = X(I): NEXT I
     FOR I = 1 TO 12: VX(I + 5) = V(I): NEXT I
     IF AVWT > VX(46) THEN VX(47) = AVWT - VX(46)
     IF AVWT <= VX(46) THEN VX(46) = AVWT: VX(47) = 0
     VX(52) = .8 * VX(49) * XP(2)
     VX(45) = VX(3) + VX(4)                    'NBR SEATS+BUNKS
     COLOR 11: LOCATE 22, 10: INPUT "ENTER RETURN....", RET

  CALL SECOND

  BT5: END SUB
```

```
SUB COMP
' basic computational module for computing at the NASA CES (WBS) level
aa93 = inx * 1.914   '80 TO 93  inx * 1.390857677#   'inf fac to move from fy85
' 1.6 estimated inf fac from fy77 to fy85
prvinx = 2.501
'2. 3.2  MAINTENANCE
'2.3.2.1  REFURBISHMENT  - prevail $FY77
CWS = .02 * XCF(3) + .05 * XCF(24)         ' assume MCF(27)=1
CRE = .1 * VX(5) * XCF(25)                 ' asumme MCF(27)=1
'CSRM = 17.377254# * VX(46) / 10 ^ 4       '??check PI in eq
'CRSRM = MCF(27) * (.1 * XCF(2) + .5 * CSRM) + .1 * XCF(26)
wbsc(2, 13) = prvinx * (CWS + CRE)
wbsc(4, 13) = lcf * wbsc(wbscc(13), 13)

UR = XP(3) * XP(2) / XP(1)       'vehicle util rate = hrs/yr per veh for HVL

'2.3.2.3 DEPOT MAINTENANCE  hypervelocity $FY85
' personnel
HP(1) = 5466 * (UR) ^ .17293 * VX(8) ^ .5389
HP(2) = 1436.4 * VX(9) ^ .30068 * VX(33) ^ .42521
HP(3) = 350.272 * VX(35) ^ .55731 * (VX(3) + VX(4)) ^ .022272
HP(4) = 4053 * VX(12) ^ .64027 * VX(15) ^ .30348
HP(5) = 256.191 * VX(11) ^ 1.2603 * (XP(3) * XP(2)) ^ .30284
HP(6) = 32661.8 * VX(11) ^ .3451 * VX(41) ^ .70715
HP(7) = 3938.44 * XP(3) ^ .36061 * VX(7) ^ .36541
HP(8) = 5.65649 * VX(2) ^ .97927 * XP(11) ^ .19409
HP(9) = .0612697 * VX(39) ^ .040297 * VX(18) ^ .6539
' hardware
HH(1) = 33844.1 * VX(8) ^ .40781
HH(2) = 939.794 * VX(2) ^ .66587 * VX(34) ^ .60526
HH(3) = 9.65239 * VX(35) ^ .44168 * VX(36) ^ .39999
HH(4) = 4.1221 * VX(47) ^ .38875 * VX(38) ^ 2.8235
HH(5) = 148.709 * VX(39) ^ .93869 * VX(12) ^ .13678
HH(6) = .738358 * VX(2) ^ 2.1815 * VX(42) ^ .15009
HH(7) = 196.918 * (VX(3) + VX(4)) ^ .0031839 * VX(7) ^ .69177
HH(8) = .00321882# * VX(2) ^ 2.1661 * VX(44) ^ .34181
HH(9) = .0560647 * VX(39) ^ .67061 * VX(2) ^ .93312
THH = 0: THP = 0
FOR I = 1 TO 9
HP(I) = aa93 * XP(2) * HP(I) / 1000000
HH(I) = aa93 * XP(2) * HH(I) / 1000000
THP = THP + HP(I)
THH = THH + HH(I)
NEXT I
wbsc(2, 24) = (THP + THH)
D1 = inx * XP(2) * VX(49) * (MCF(13) * XCF(7) + XCF(26)) / 1000000
IF XP(12) = 0 THEN wbsc(2, 24) = D1
wbsc(4, 24) = lcf * wbsc(wbscc(24), 24)


'2.3.2.4  MODIFICATIONS   from Cost of Ownership Model
wbsc(2, 25) = inx * .004494 * wbsc(wbscc(6), 6)
wbsc(4, 25) = lcf * wbsc(wbscc(25), 25)

'2.3.2.5  VERIFICATION & CHECKOUT     No longer used
'Wbsc(4, 26) = lcf * wbsc(wbscc(26), 26)


' 2.3.3 LOGISTICS
'    2.3.3.1 SPARES - initial
```

```
'       AMLS ($FY93) - hardware
    SI = inx * (1 - MCF(3)) * MCF(2) * MCF(37) * XCF(4) / 1000000
'       HYPERVEL - ($FY85)
HS(1) = 4.08905 * VX(8) ^ 1.4795 * VX(48) ^ .8881
HS(2) = 1.14042 * VX(18) ^ 1.0393
HS(3) = .025 * wbsc(1, 6) / XP(1)
    ' W(3) = 55860.45   ' !!!!!!!!!!!
HS(4) = 9675.31 * VX(47) ^ .78372 * (W(3) / VX(7)) ^ .37412
HS(5) = 932.337 * VX(48) ^ .62003 * VX(12) ^ .7465
HS(6) = 3.1879 * VX(2) ^ 1.8749 * VX(48) ^ .8138
HS(7) = 2.86158 * (VX(17) * (VX(3) + VX(4))) ^ .6701 * VX(12) ^ 1.0107
HS(8) = 14.4453 * VX(48) ^ .72729 * VX(7) ^ .6217
HS(9) = .00514174# * VX(8) ^ 1.4795 * VX(48) ^ .8881
THS = 0
FOR I = 1 TO 9
HS(I) = aa93 * HS(I) / 1000000
THS = THS + HS(I)
NEXT I

' recurring spares AMLS - ($FY93)
   RS = inx * XP(2) * VX(49) * MCF(4) * XCF(4) * MCF(2) / 1000000
'  HYPERVEL - ($FY85)
HR(1) = 1310.2 * UR ^ .44611 * VX(8) ^ .42599
HR(2) = 2877.49 * VX(9) ^ .9313 * VX(32) ^ .2789
HR(3) = 10.6276 * VX(35) ^ .20537 * VX(36) ^ .70128
HR(4) = 10.799 * VX(12) ^ .89189 * VX(46) ^ .68652
HR(5) = 115.132 * VX(39) ^ .9355 * VX(40) ^ .95695
HR(6) = .290026 * VX(2) ^ 2.3754 * VX(41) ^ .21649
HR(7) = 57.1462 * XP(3) ^ .29514 * VX(7) ^ .66886
HR(8) = .0344495 * VX(44) ^ .56086 * VX(2) ^ 2.1661
HR(9) = .0938672 * VX(36) ^ .57147 * VX(35) ^ .36911
THR = 0
FOR I = 1 TO 9
HR(I) = aa93 * XP(2) * HR(I) / 1000000
THR = THR + HR(I)
NEXT I

IF XP(12) = 0 THEN wbsc(2, 26) = (SI + RS) ELSE wbsc(2, 26) = (THS + THR)
IF XP(12) = 0 THEN wbsc(4, 26) = lcf * RS + SI ELSE wbsc(4, 26) = lcf * THR + TH
IF wbscc(26) = 1 THEN wbsc(4, 26) = lcf * wbsc(1, 26)

'2.3.3.2  EXPENDABLES  based upon Cost of Ownership model - tot EOQ
TEOQ = -29.9 + .039 * (VX(49) * XP(2) * (1 - MCF(4)) * XCF(4))
IF TEOQ < 0 THEN TEOQ = 10000
wbsc(2, 27) = inx * TEOQ / 1000000
wbsc(4, 27) = lcf * wbsc(wbscc(27), 27)

' 2.3.3.3 CONSUMABLES - AMLS
NC = 0
FOR I = 18 TO 23
NC = NC + XCF(I) * MCF(I + 1)
NEXT I
RC = NC * XP(2) + (VX(3) + VX(4)) * (XP(3) / 48) * XCF(12) * XP(2)
NC = 3 * NC
NC = inx * NC / 1000000: RC = inx * RC / 1000000
wbsc(2, 28) = (NC + RC)
IF wbscc(28) = 2 THEN wbsc(4, 28) = NC + lcf * RC ELSE wbsc(4, 28) = lcf * wbsc(

' 2.3.3.4 INVENTORY MANAGMENT & WAREHOUSE
' AMLS
```

```
TSPARES = MCF(37) * MCF(34) * MCF(25)
NIMWC = TSPARES * MCF(18) * XCF(8)
RSPARES = XP(2) * VX(49) * MCF(4)
RIMWC = XP(2) * VX(49) * MCF(5) * MCF(18) * XCF(8)
NIMWC = inx * NIMWC / 1000000: RIMWC = inx * RIMWC / 1000000
wbsc(2, 29) = (NIMWC + RIMWC)
wbsc(4, 29) = NIMWC + lcf * RIMWC
IF wbscc(29) = 1 THEN wbsc(4, 29) = lcf * wbsc(1, 29)

' 2.3.3.5   TRAINING - AMLS
'N1 = VX(51) * MCF(2) * (1 - MCF(3)) * XCF(9) * MCF(15) * MCF(17) + MCF(15) * MC
'N2 = XCF(9) * MCF(15) * MCF(32) * MCF(17) * VX(51) + MCF(17) * MCF(15) * MCF(35
'N3 = VX(52) * MCF(38) * MCF(2) * (1 - MCF(3)) * XCF(9) * MCF(15) * MCF(7) + MCF
'N4 = XCF(9) * MCF(15) * MCF(32) * MCF(7) * VX(52) * MCF(5) + MCF(7) * MCF(15) *
TECHS = CINT((XP(2) / 12) * VX(49) * MCF(38) * MCF(13) / ((1 - X(12)) * X(11)))
N1 = VX(51) * MCF(17) * 3 * XCF(6) + 2 * 39 * MCF(17) * XCF(5)
N2 = MCF(35) * MCF(11) * MCF(17) * XCF(5)
N3 = VX(53) * MCF(38) * MCF(9) * XCF(9) + TECHS * MCF(7) * XCF(7)
N4 = TECHS * MCF(11) * MCF(7) * XCF(7)

N1 = inx * N1 / 1000000: N2 = inx * N2 / 1000000
N3 = inx * N3 / 1000000: N4 = inx * N4 / 1000000
wbsc(2, 30) = (N1 + N2 + N3 + N4)
wbsc(4, 30) = N1 + lcf * N2 + N3 + lcf * N4
IF wbscc(30) = 1 THEN wbsc(4, 30) = lcf * wbsc(1, 30)

' 2.3.3.6  DOCUMENTATION
'   AMLS
'M1 = VX(52) * MCF(2) * (1 - MCF(3)) * MCF(9) * XCF(27) * MCF(14)
'M2 = VX(52) * MCF(9) * XCF(13) * MCF(10) * MCF(33)
'M3 = VX(52) * MCF(38) * MCF(2) * (1 - MCF(3)) * MCF(8) * XCF(27) * MCF(14)
'M4 = VX(52) * MCF(5) * MCF(2) * MCF(8) * XCF(13) * MCF(10) * MCF(33)
M1 = VX(51) * MCF(40) * XCF(27)
M2 = VX(51) * MCF(40) * XCF(27) * MCF(12)
M3 = VX(53) * MCF(38) * MCF(9) * MCF(8) * XCF(27)
M4 = VX(53) * MCF(38) * MCF(9) * MCF(8) * XCF(27) * MCF(10)

M1 = inx * M1 / 1000000: M2 = inx * M2 / 1000000
M3 = inx * M3 / 1000000: M4 = inx * M4 / 1000000
wbsc(2, 31) = (M1 + M2 + M3 + M4)
wbsc(4, 31) = M1 + lcf * M2 + M3 + lcf * M4

'  HYPERVEL
HD(1) = 401.439 * VX(18) ^ .6394
HD(2) = 214.6 * XP(11) ^ .6664 * VX(19) ^ .30877
HD(3) = .01 * wbsc(1, 6) / XP(1)
HD(4) = 142345 * (VX(46)) ^ .091207
HD(5) = 38.7703 * VX(12) ^ 1.0292
HD(6) = 741.81 * VX(10) ^ .95341
HD(7) = 29077.9 * (VX(46)) ^ .18719
HD(8) = 15.5429 * VX(45) ^ .70674 * XP(11) ^ .9167
HD(9) = .517318 * VX(18) ^ .6394
THD = 0
FOR I = 1 TO 9
HD(I) = aa93 * HD(I) / 1000000
THD = THD + HD(I): NEXT I
IF XP(12) = 1 THEN wbsc(2, 31) = THD: wbsc(4, 31) = lcf * wbsc(2, 31)
IF wbscc(31) = 1 THEN wbsc(4, 31) = lcf * wbsc(1, 31)
```

```
' 2.3.3.7  TRANSPORTATION
' AMLS
T1 = XP(1) * VX(1) * MCF(26) * MCF(39) * XCF(15)
T2 = XP(2) * VX(1) * MCF(26) * MCF(28) * XCF(14) + XP(2) * VX(49) * (VX(1) / VX(
T1 = inx * T1 / 1000000: T2 = inx * T2 / 1000000
wbsc(2, 32) = (T1 + T2)
wbsc(4, 32) = T1 + lcf * T2
IF wbscc(32) = 1 THEN wbsc(4, 32) = lcf * wbsc(1, 32)

' 2.3.3.8  SUPPORT EQUIPMENT  AMLS
'S1 = MCF(5) * (1 - MCF(3)) * ((XP(2) * VX(50)) / (18 * 4 * 60)) * XCF(11)
'S1 = S1 + XCF(29) + MCF(36) * MCF(5) * VX(52) * MCF(1)
'S2 = S1 * MCF(29)
S1 = 1000 * XCF(11) * (VX(1) / 165000) * (VX(51) / 39) * (XP(2) / 18)
S2 = .1 * S1
S1 = inx * S1 / 1000000: S2 = inx * S2 / 1000000

NGSE = (VX(1) / 178289) * MCF(2) * (1 - MCF(3)) * ((XP(2) * VX(50)) / (12 * 4 *
RGSE = NGSE * MCF(29)
NGSE = inx * NGSE / 1000000
RGSE = inx * RGSE / 1000000
GSE = NGSE + RGSE

wbsc(2, 33) = (S1 + S2) + GSE
wbsc(4, 33) = S1 + lcf * S2 + NGSE + lcf * RGSE

' support equip -hypervel
HVLRSE = 0: HVLNSE = 0
FOR I = 1 TO 9
DC(I, 7) = (XP(1) / 4) * DC(I, 7) / 1000000
DC(I, 9) = .2 * DC(I, 7)
HLVNSE = HLVNSE + DC(I, 7)
HLVRSE = HLVRSE + DC(I, 9)
NEXT I
IF XP(12) = 1 THEN wbsc(2, 33) = HLVRSE + HLVNSE: wbsc(4, 33) = HLVNSE + lcf * H
IF wbscc(33) = 1 THEN wbsc(4, 33) = lcf * wbsc(1, 33)

'  NAVAL FIXED WING
'  wbsc(2,33) = .1965*(60*XP(3))^.4517/1000000

' 2.3.3.9  ILS MANAGEMENT
NILSM = MCF(16) * (SI + NC + NIMWC + NGSE + N1 + N3 + M1 + M3 + T1 + S1)
RILSM = MCF(31) * (D1 + RS + RC + RIMWC + RGSE + N2 + N4 + M2 + M4 + T2 + S2)
wbsc(2, 34) = NILSM + RILSM
wbsc(4, 34) = NILSM + lcf * RILSM
IF wbscc(34) = 1 THEN wbsc(4, 34) = lcf * wbsc(1, 34)

' 2.3.4  SYSTEM SUPPORT
'   2.3.4.1  SUPPORT STAFF
'  HYPERVEL  FY85
AC = .21458 * VX(3) ^ 1.6422 * XP(1) ^ .89681
CS = .21458 * (UR) ^ .50621 * XP(1) ^ .89225
AC = aa93 * AC: CS = aa93 * CS
HYPS = .2 * (AC + CS)
' PREVAIL
PRVS1 = .05 * wbsc(wbscc(12), 12)
PRVS2 = .03 * XCF(17)
wbsc(2, 36) = HYPS + PRVS1
wbsc(4, 36) = lcf * wbsc(wbscc(36), 36)
```

```
'2.3.4.3  COMMUNICATIONS  (i=40)

' 2.3.4.4   BASE OPS  - HYPERVEL  FY85 (i=41)

'installation support from Cost of Ownership Model
OPER = XP(1) * VX(3) + .8 * (XP(1) * VX(3))
ISPT = .156 * XCF(2) * 40 * 52 * (MCF(35) + OVH + OPER)'personnel cost
MSPT = prvinx * 768 * (MCF(35) + OVH + OPER)'hardware costs
TOSPT = inx * (ISPT + MSPT) / 1000000

'SEC = inx * .07 * (AC + CS) / 1000000     ' security
wbsc(2, 39) = 4 * TOSPT / 6
wbsc(2, 38) = TOSPT / 6

wbsc(4, 38) = lcf * wbsc(wbscc(38), 38)
wbsc(4, 39) = lcf * wbsc(wbscc(39), 39)

'2.3.4.5   launch post launch cleanup   not currently used
'wbsc(4, 42) = lcf * wbsc(wbscc(42), 42)

END SUB
```

```
SUB REPORT
TOP: CLS
PRINT : PRINT TAB(25); "REPORT GENERATOR MENU": PRINT
COLOR 11
PRINT TAB(15); "NBR"; TAB(35); "SELECTION": PRINT
PRINT TAB(15); "1........PRINT INPUT DATA"
PRINT TAB(15); "2........PRINT WBS SUMMARY REPORT"
PRINT TAB(15); "3........PRINT HYPERVELOCITY MODEL COSTS"
PRINT TAB(15); "4........PRINT LOGISTICS MODEL COSTS"
PRINT TAB(15); "5........PRINT ORG MANPOWER COSTS"
PRINT TAB(15); "6........PRINT FACILITIES COST"
PRINT TAB(15); "7........PRINT SYSTEM SUPPORT COST "
PRINT TAB(15); "8........PRINT R&D/ACQ COSTS-PREVAIL"
PRINT TAB(15); "9........PRINT TOTAL OUTPUT"
PRINT TAB(15); "10.......PRINT TOTAL INPUT/OUTPUT"
PRINT TAB(15); "11.......WRITE INPUT/OUTPUT TO A FILE"
COLOR 3
PRINT TAB(15); "RETURN....main menu"
COLOR 11
LOCATE 22, 10: COLOR 13: PRINT "VEHICLE/FILE NAME IS  "; VNAM$
COLOR 10: LOCATE 18, 20: INPUT "ENTER SELECTION"; NDO
IF NDO <= 0 OR NDO > 11 THEN EXIT SUB
LOCATE 19, 20: INPUT "ENTER TITLE OF REPORT"; RTITLE$
IF NDO = 1 THEN CALL ECHO
IF NDO = 2 THEN CALL PRINTWBS
IF NDO = 3 THEN CALL PRINTHYP
IF NDO = 4 THEN CALL PRINTLOG
IF NDO = 5 THEN CALL PRINTMAN
IF NDO = 6 THEN CALL PRINTFAC
IF NDO = 7 THEN CALL PRINTSYS
IF NDO = 8 THEN CALL PRINTACQ
IF NDO = 9 THEN GOSUB ALL
IF NDO = 10 THEN GOSUB ALL
IF NDO = 11 THEN CALL WFILE
GOTO TOP
ALL: 'CALL ALL PRINT MODULES
IF NDO = 10 THEN CALL ECHO
CALL PRINTWBS
CALL PRINTHYP
CALL PRINTLOG
CALL PRINTMAN
CALL PRINTFAC
CALL PRINTSYS
CALL PRINTACQ
RETURN

END SUB
```

```
SUB WFILE

CLS : COLOR 11
LOCATE 10, 10: PRINT "DATA WILL BE WRITTEN TO "; VNAM$; ".LCO IN ASCII FORMAT"
PRINT : INPUT "ENTER RETURN TO CONTINUE OR A POSITIVE NBR TO ABORT"; RET
IF RET > 0 THEN EXIT SUB
OPEN VNAM$ + ".LCO" FOR OUTPUT AS #3
PRINT #3, TAB(5); RTITLE$; TAB(65); DATE$
PRINT #3,
PRINT #3, TAB(25); "INPUT DATA FOR COSTING "; VNAM$
PRINT #3,
PRINT #3, TAB(30); "SYSTEM PARAMETERS"
PRINT #3,
PRINT #3, TAB(10); "NBR"; TAB(20); "PARAMETER"; TAB(50); "VALUE"
PRINT #3,
FOR I = 1 TO 12

        PRINT #3, TAB(10); I; TAB(20); P$(I); TAB(50);
        IF I = 9 THEN
                PRINT #3, USING "###.## %"; XP(I) * 100
        ELSE
                PRINT #3, USING "#####"; XP(I)
        END IF
NEXT I
PRINT #3,
PRINT #3, TAB(30); "COST FACTORS & RATES TABLE": PRINT #3,
PRINT #3, TAB(5); "Note: all costs should be in 1993 year dollars"
PRINT #3,
PRINT #3, TAB(5); "NBR"; TAB(15); "CATEGORY"; TAB(60); "VALUE"
PRINT #3,
FOR I = 1 TO 29
        IF I = 6 OR I = 17 OR I = 26 OR I = 28 THEN GOTO SKYP
        PRINT #3, TAB(5); I; TAB(15); CF$(I); TAB(57);
        PRINT #3, USING "$########.#####"; XCF(I)

SKYP:  NEXT I
PRINT #3,
PRINT #3, TAB(5); "VEHICLE IS ";
PRINT #3, TAB(35); "DESIGN/PERFORMANCE VARIABLES ": PRINT #3,
PRINT #3,
PRINT #3, TAB(5); "NBR"; TAB(15); "VARIABLE"; TAB(55); "VALUE"

FOR I = 1 TO 53
        IF I = 14 OR I >= 20 AND I < 32 OR I = 37 OR I = 43 THEN GOTO SY2
        PRINT #3, TAB(5); I; TAB(15); VX$(I); TAB(55);
        PRINT #3, USING "#######"; VX(I)
SY2: NEXT I
PRINT #3,
PRINT #3, TAB(5); "VEHICLE IS ";
PRINT #3, TAB(30); "MISCELLANEOUS FACTORS"
PRINT #3,
PRINT #3, TAB(5); "NBR"; TAB(15); "CATEGORY"; TAB(60); "VALUE"
PRINT #3,
FOR I = 1 TO 39

        PRINT #3, TAB(5); I; TAB(15); MF$(I); TAB(55);
        PRINT #3, USING "#########.##"; MCF(I)
NEXT I

PRINT #3, TAB(30); "NBR CREWS ASSIGNED"
```

```
PRINT #3, TAB(1); "SUBSYSTEM"; TAB(20); "CREWS ASSIGNED"; TAB(40); "CREW SIZE";
PRINT #3,
FOR I = 1 TO 9
X = X + INT(CZ(I) * SC(I) + .9999)
PRINT #3, TAB(1); SWBS$(I); TAB(20); CZ(I); TAB(40); SC(I); TAB(60); INT(CZ(I) *
NEXT I
PRINT #3, TAB(1); TAB(1); "SCHED MANPWR"; TAB(60); CZ(10)
PRINT #3, : PRINT #3, TAB(5); "TOT ORG MAINT PERS- direct labor"; TAB(55); X + C
PRINT #3, : PRINT #3, TAB(25); "SUBSYSTEM WEIGHT TABLE"
PRINT #3,
PRINT #3, TAB(5); "Note: weights are initialized from RAM model"
PRINT #3,
PRINT #3, TAB(10); "NBR"; TAB(20); "SUBSYSTEM"; TAB(50); "WEIGHT"
FOR I = 1 TO 33
        'IF W(I) = 1 THEN GOTO SYP
        PRINT #3, TAB(10); I; TAB(20); wbs$(2, I); TAB(50);
        PRINT #3, USING "#####"; W(I)
SYP: NEXT I
PRINT #3, : PRINT #3, TAB(10); "TOTAL DRY WEIGHT"; TAB(50); VX(1)

PRINT #3,
PRINT #3, TAB(20); "Cost Element Structure": PRINT #3,
PRINT #3, TAB(5); "Note:  costs listed are direct input and are not computed by
PRINT #3,
PRINT #3, TAB(5); "nbr"; TAB(15); "WBS"; TAB(55); "Cost [93 M$]"
PRINT #3,
FOR I = 1 TO 44

        IF wbscc(I) = 2 THEN GOTO sky3
        IF I = 4 OR I = 11 OR I = 12 OR I = 20 OR I = 26 OR I = 36 OR I = 42 OR
        PRINT #3, TAB(5); I; TAB(13); wbs$(1, I); TAB(55); ,
        PRINT #3, USING "######.###"; wbsc(3, I)

sky3: NEXT I
PRINT #3,
ia = 1: ib = 42
IF XP(6) = 1 THEN yr = year ELSE yr = XP(7) + XP(4)
PRINT #3, TAB(5); "WBS COST SUMMARY FOR "; VNAM$; " OVER A "; XP(4); " YR SYSTEM
IF XP(6) = 1 THEN PRINT #3, TAB(5); "Life cycle costs are in constant"; year; "d
PRINT #3, ""; TAB(2); "WBS"; TAB(38); "Cost [M year"; year; "$]"; TAB(62); "LCC
PRINT #3,
FOR I = ia TO ib

        IF I = 4 OR I = 11 OR I = 23 OR I = 35 OR I = 40 OR I = 41 OR I = 42 THE
        PRINT #3, TAB(1); wbs$(1, I); TAB(30); ,
        PRINT #3, USING "####.###  ##########.###"; wbsc(wbscc(I), I); wbsc(4, I

NEXT I

'
PRINT #3, TAB(30); "TOTAL"; TAB(42);
PRINT #3, USING "######.###  ##########.###"; totd; lctot
CLOSE #3

END SUB
```